System Optimization Review of the Associated Ditch System in Kearny and Finney Counties, Kansas

Prepared for

Southwest Kansas Groundwater Management District

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Introduction

In October 2011, the Southwest Kansas Groundwater Management District No. 3 (GMD3), working with an Advisory Committee from the Associated Ditches of Kansas (the "Associated Ditches"), contracted with the BOR to perform a System Optimization Review (SOR) for the Associated Ditches canal system and the Arkansas River in the project area. The Associated Ditches is an organization whose members divert irrigation water from the Arkansas River in Kearny and Finney Counties, Kansas between the towns of Kendall and Garden City. The firms of Spronk Water Engineers and GEI Consultants, Inc. were retained to complete this SOR.

The overall purpose of the SOR is to evaluate the water supply system for potential efficiency improvements and then to identify potential projects and make a preliminary evaluation of the costs and benefits. The plan of study included the following:

- Document water supplies and water use facilities in the study area.
- Identify components of the water supply system for which improvements or system enhancements could improve water use efficiencies.
- Identify alternatives to address water use inefficiencies.
- Develop and configure conceptual projects to accomplish identified alternatives. Components of project description included location, sizing and operation.
- Evaluate benefits, in terms of water supply or efficiency savings, and preliminary costs.

The SOR was conducted in collaboration with the water users who would benefit from potential water use efficiency improvements.

Water Supply System

The project area includes extensive irrigation system development that relies on both flows in the Arkansas River diverted by canals and groundwater pumped from the regional High Plains Aquifer. The Associated Ditches water users divert from the Amazon Canal, the Great Eastern Canal, the South Side Ditch, the Garden City Ditch and the Farmers Ditch. These canals have been in existence since the late 1800's. Surface water diverted by the canals is used for gravity and sprinkler irrigation on approximately 44,000 acres in recent years, but these canals historically served approximately 70,000 acres. The surface water supply from the Arkansas River is highly variable from year to year. Flow at the Colorado-Kansas stateline has ranged from 35,900 to 536,600 ac-ft/yr. over the study period of 1982 -2011. Flow in each of the two years, 2012 and 2013, was less than the minimum annual flow in the study period and there have been years when no river flow was available for diversion.

The river recharges the High Plains aquifer in the study area. Losses of surface flow to the aquifer reduce the available supply for diversion at the lower end of the project area. The limited supply of water in the river is shared by the individual canals and all the canals are short of a full supply during most years. The Farmers Ditch is the most downstream facility in the study area, and typically suffers the greatest shortage of water supply.

An emphasis for the SOR has been to enhance the ability to deliver water for diversion at the Farmers Ditch Headgate. An additional objective, which was identified during the project definition phase, was to increase the amount of surface water used in the South Side Ditch service area by center pivot sprinklers. Diversion of high river flows for managed recharge in the project area that would avoid some of the river channel losses downstream of the project area has also been identified., Consistent with SOR objectives, opportunities for renewable energy enhancement, in this case small-scale hydro development, were also evaluated.

Overview of Projects Evaluated

The SOR was focused on alternatives identified by the Associated Ditches Advisory Committee. Several of these alternatives evolved from the results of earlier investigations, as described in the main report.

Project alternatives identified and evaluated in the SOR include:

- Alternative Delivery systems (ADS) to the Farmers Ditch to avoid the effects of high stream transit losses. Alternatives included the South Side Ditch, the Great Eastern ditch system and a constructed low-flow channel along the Arkansas River.

- Installation of sprinkler pits in the South Side Ditch service area to facilitate use of surface water with center pivots. Sprinkler pits would facilitate use of surface water and reduce groundwater pumping. Benefits would include reduced pumping costs and less reliance on the groundwater source.

- Managed recharge project, diverting high flows in the Arkansas into a new canal to a recharge site south of the Arkansas River. Water would be diverted to the recharge area when river flows exceed those required to satisfy downstream water rights.

- Small-scale hydropower installations.

Both the ADS to the Farmers Ditch and the use of surface water in the South Side Ditch service area would reduce the amount of irrigation pumping from the regional aquifer. These projects would provide the benefit of reducing groundwater pumping. The managed recharge project would enhance aquifer storage and provide increased supplies by storing surface water for later use by pumping.

Conceptual designs were developed and costs were estimated for each project. The main report provides a comparison of costs and water savings expected from each project. Other potential benefits are identified. Further, more-detailed investigations, which are identified in the report, will be required if decisions are made to move toward implementation of these potential projects.

Summary of Project Evaluations

Alternate Delivery to Farmers Ditch – Southside Project: The amount of water available for diversion at the Farmers would be increased by using more efficient delivery through the South Side Ditch, discharging to the river 4,400 feet upstream of the Farmers headgate. This practice has already operated to a limited extent in recent years. Using the South Side Ditch would produce enhanced supply, estimated to range from 5,600 to 6,400 ac-ft/yr when operated. The diversion would be operated in some, but not all, years depending on river conditions. Farmers Ditch operations would need to be integrated with the South Side Ditch operations through an agreement or operating plan that would require some rotation between the two systems. The water would be delivered to the river through the South Side return channel constructed in 2010. The SOR alternative identified a siphon across the river and a new channel extending 4,400 foot from the outlet to the Farmers headgate at an estimated cost of $2.2 million, of which $1.9 million is for the siphon. It may be possible to eliminate the siphon component and use a short reach of the river for conveyance. However, this option would require frequent maintenance.

Alternate Delivery to Farmers Ditch – Northside Project: These ADS alternatives would deliver water through the Great Eastern Canal system to the Farmers Ditch Headgate. Two alternate locations on the Great Eastern Canal were identified for diversion into a pipeline connecting the Great Eastern Canal with the Farmers Ditch. Diversion at the upstream site would rely to a lesser extent on the Great Eastern, with 2.5 miles of large diameter concrete pipeline to the Farmers Ditch. The second alternative would divert water into the Farmers Ditch through a smaller diameter PVC pipe at a location very close to the Farmers Ditch with greater reliance on the Great Eastern Canal for conveyance. As with the Southside ADS, an operating agreement to facilitate integrated operation with the Great Eastern Canal would be necessary. The costs for the two alternatives are $6.4 million for the upstream pipeline and $0.78 million for the downstream pipeline. The yields were estimated at 3,800 to 5,200 ac-ft/yr in years when the ADS is in operation.

An alternate way of improving supply to the Farmer Ditch is to reduce river transit losses. **River Flow Restoration:** A 2.5–mile-long concrete-lined channel, with a capacity of 200 cfs, could be constructed along a reach of the Arkansas River that is known to have high seepage losses. The estimated increased yield and supply to the Farmers Ditch is 2,100 to 3,200 ac-ft/yr. The cost of this project would be $1.7 million. This project is likely to entail additional permitting challenges, in comparison to the ADS options, because it will require construction adjacent to the river channel.

The Bear Creek Valley Recharge Project: This project is currently configured as a 7 mile-long unlined canal supplied by a new diversion facility on the Arkansas River, located 2 miles upstream of the diversion works for the South Side Ditch. The facility would divert high flows in excess of the needs of existing canals. This facility may potentially divert winter period flows when they are available and in excess of minimum river flow requirements that will need to be determined. This project would require a new water right to divert from the Arkansas River and would be operated in a manner to avoid interference with downstream water rights and minimum streamflows. It was determined that water would be available for diversion in some, but not all, years of the 1982-2011 study period. Deliveries would be made to a natural topographic depression. Because the soils in this area are very permeable, minimal recharge site development is believed to be necessary. Further study of this project is recommended to evaluate:

- Benefits of aquifer recharge at this site;
- Refined estimates of yields from river diversions;
- Potential permitting requirements;
- Water right considerations;
- More detailed site investigations for the recharge site; and
- Alternate sizing of the diversion canal.

The cost of a 700 cfs diversion and conveyance facility is $8 million. The estimated yield for recharge is 15,000 ac-ft/yr, with diversions available approximately 40% of the years, based on hydrology from a 30-year study period.

Sprinkler Pits in the South Side Ditch Service Area: These projects would facilitate use of surface water by center-pivot sprinklers. The pits would be situated near the existing canal or laterals in order to minimize the cost of pipelines to supply water to the pits. Significant project elements include pump systems, gate structures on the ditch and pipeline from the pits to the sprinklers. The project efficiency would be enhanced by locating the pits to serve multiple sprinklers. When multiple water users access a single pit, coordinated operation would be necessary. Further investigation of this project would include preliminary siting and sizing of pits and more-detailed engineering of the project components. The cost per pit was estimated to be $516,000 per installation, assuming four sprinklers per pit. The estimated savings in pumping costs are preliminarily estimated at $8,500 /installed pit. These savings would be limited by available surface water supply, which is variable from year to year and may not be available each year.

Small-Scale Hydropower was evaluated at several possible sites. The Frontier Ditch wasteway, located upstream in Hamilton County, was evaluated for costs and energy production. The flow at this site is somewhat steady over the irrigation season. Other sites in conjunction with the ADS installations for the South Side and Great Eastern ditches were also evaluated. It was concluded that hydropower development at these sites would not be economically viable because of the limited and undependable flow for energy generation.

Conclusions and Recommendations

There are opportunities to improve water use efficiency in the study area with implementation of one or more projects that have been identified. The conceptual designs are adequately developed to define the overall scope and potential benefits of the projects and to provide preliminary opinions on the construction costs. Further studies are recommended for those projects determined to be viable by the GMD3 and Advisory Committee. The projects should be ranked by the project proponents based on operational feasibility, as well as estimated costs and yields. Projects considered worthy of further consideration will require specific site investigations to refine the project development components and the estimated costs. Assumptions made to estimate the potential benefits of the proposed projects should be evaluated in more detail and refined for those alternatives deemed to be viable.

1.0 Introduction

1.1 Background

In February 2010, the US Department of the Interior established the WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. The Bureau of Reclamation (BOR) participates in the program through grants, studies, and technical assistance and expertise. As part of the program, the BOR provides funds for System Optimization Review (SOR) studies. and partners with organizations that have water or power delivery authority to examine system-wide efficiencies within their delivery systems. The purposes of the SOR are to identify inefficiencies within the delivery systems and develop a plan, including identification of physical improvements, to remedy some or all of the inefficiencies. The SOR also considers potential renewable energy components, potential energy savings from increased efficiencies, and threatened and endangered species concerns.

The Associated Ditches of Kansas ("Associated Ditches") is an organization whose members divert irrigation water from the Arkansas River in Kearny and Finney Counties, Kansas between the United States Geological Survey (USGS) stream gage near the town of Kendall and the USGS stream gage near Garden City. The ditches represented by the Associated Ditches are the Amazon Canal, the Great Eastern Canal, the South Side Ditch, the Garden City Ditch and the Farmers Ditch. In October 2011 the Southwest Kansas Groundwater Management District No. 3 (GMD3), working with an advisory committee from the Associated Ditches, contracted with the BOR to perform a SOR for the Associated Ditches canal system and the Arkansas River in the project area. There is a limited supply of water in the river that is shared by the individual canals and the Farmers Ditch typically suffers the greatest shortages of water supply. The SOR study identifies measures to minimize water losses due to inefficiencies so that additional water can be supplied to the Farmers Ditch for irrigation. **Figure 1** is a general location map showing the project area and the general outline of the service area of the Associated Ditches.

The purposes of the SOR are to: identify and quantify major sources of transit losses in the project area; evaluate several known supply and management issues; develop alternatives for improving efficiency and delivery methods; investigate the possibility of generating renewable energy; and identify effects of proposed alternatives on threatened and endangered species in the project area. The SOR report describes the canal systems of the Associated Ditches and the adjacent drainage area of the Arkansas River, summarizes the study methods and the information gathered, and describes the issues, priorities and potential improvements that were identified.

1.2 Project Area

The Arkansas River enters western Kansas in Hamilton County, and flows eastward about 40 miles to the project area in Kearny and Finney Counties. The river in Kearny and Finney Counties is underlain by the Ogallala (High Plains) Aquifer. The river traverses approximately 85 miles from the Stateline to the Finney-Gray County line. Surface flows in this area originate primarily from Colorado and include both unregulated flows at the Stateline and releases from John Martin Reservoir in Colorado made at the request of the canals in Kansas for irrigation supply. The Project Area is defined by the Arkansas River in Kearny and Finney Counties, Kansas between the town of Kendall and Garden City, and the service areas of the Associated Ditches that divert from the river in this vicinity. Although it is not within the Project Area, the Frontier Ditch in Hamilton County near the Stateline has been included in the study investigations for the purpose of evaluating development of low-head hydropower. **Figure 2** is a map of the study area, showing the reach from Kendall to Garden City and the ditch service areas.

Water use in the area includes direct diversions from the Arkansas River for irrigation by the Associated Ditches and pumping from wells tapping both the alluvial aquifer along the river and the Ogallala Aquifer. The canals in Kansas have been in existence since the late 1800's. Surface water diverted by the canals is used for gravity and sprinkler irrigation on approximately 44,000 acres in recent years, but historically served approximately 70,000 acres. This includes approximately 2,200 acres irrigated under the Frontier Ditch near the Stateline. The balance is located between Kendall and Garden City in Kearny and Finney Counties. Near Kendall, the river crosses the Bear Creek fault and is in an area of direct connection to the Ogallala Aquifer from that point east. Water diverted for irrigation also recharges the Ogallala aquifer underlying the canal service areas. One reservoir, Lake McKinney, is located in the service area and provides storage for lands served by the Great Eastern Ditch.

1.3 Scope of Work

The basic Scope of Work for the study was to evaluate the system of canals in the study area to identify and quantify system inefficiencies. The study was originally planned to include a substantial data collection component, including measurement of stream channel losses and seepage losses within the ditch systems. The river between Kendall and Garden City is generally a losing reach and deliveries of water via the stream channel to the last diversion point near Garden City incurs substantial losses during certain flow conditions. However, the years subsequent to the initiation of the study were years of extremely limited water supply, resulting in the inability to collect field measurements specified in the original Scope of Work for the SOR.

Reclamation was notified of this situation (Progress Reports 4 and 5). In July, 2013 it was decided to complete the study with available data and information. A list of potential efficiency improvement alternatives to address various issues of system efficiency was prepared and investigations were conducted from July, 2013 to June, 2014 to configure the potential projects, including size and location, and to develop project cost estimates. Estimates of water savings or yields attributable to each alternative were prepared. The water savings that could be achieved by avoided transit loss were estimated from available flow data.

Project alternatives were identified and developed in consultation with GMD3 and the Advisory Committee. Specific goals to improve system efficiency were first developed. Potential projects to address were then identified for evaluation. Two on-site meetings were conducted with the committee; the first to obtain background and familiarity with the system and water supply issues; and the second to observe potential project components and constraints in the field.

The projects include three alternatives intended to address the river conveyance losses at low flows for the downstream diversions at the Farmers Ditch. There are two alternative delivery system (ADS) projects that would utilize existing canals diverting near Kendall to deliver water to the Farmers at times of low river flows when conveyance losses are greatest.

A conceptual project was identified to reduce the reliance on groundwater under the South Side Ditch service area, using on-farm irrigation technology that has been implemented with some success on the north side of the river. This alternative involves construction of on-farm surface water regulation pits for supplying center pivot sprinklers.

A project involving implementation of managed aquifer recharge is identified in the SOR. This alternative envisions diverting high flows from the Arkansas River near Kendall at times when the Ditches are supplied and excess river flows would be available. This project would require construction of a new diversion works and conveyance canal on the south side of the river. This recharge site is one that was previously identified and investigated for small scale recharge for the Kansas Water Office and information developed in that study has been relied on for this SOR.

1.4 Overview of Study

The overall purpose of the SOR is to evaluate the water supply system for potential efficiency improvements and then to identify potential projects and make a preliminary evaluation of the costs and benefits. The SOR was conducted in collaboration with the affected water users. The initial phase of the study consisted of investigation and meetings to identify system inefficiencies and potential projects to address them. An initial meeting and site visit was conducted in 2011 to discuss the water supply issues, results of previous investigations and observe the facilities. An emphasis for this project has been to enhance the ability to deliver water for diversions at the Farmers Ditch, the most downstream facility in the study area, to reduce the amount of water lost in transit in the river. An additional objective identified during the project identification phase was to increase the amount of surface water used in the South Side Ditch service area by center pivot sprinklers. Diversion of high river flows for managed recharge in order to reduce river channel losses has also been identified and investigated. As part of the study, opportunities for small-scale hydro development were also evaluated.

The project focused on evaluation of alternatives identified by the Associated Ditches Advisory Committee. Several of these alternatives evolved from the results of earlier investigations. For example, alternative delivery to the Farmers Ditch had been previously investigated in a 2005

Reconnaissance Study (Ref. 2) and the 2007 South Side Ditch feasibility study (Ref. 3). The SOR is an extension of these earlier studies to incorporate pipeline conveyance from northside alternative delivery sites on the Great Eastern Canal, or a channel constructed along the Arkansas River for deliveries from the South Side Ditch.

Three alternatives were identified in the SOR. The first would be an extension of work that was previously completed to construct a return channel at the end of the South Side Ditch to the Arkansas River one mile upstream of the diversion headgate of the Farmers Ditch. This channel was utilized in 2010 and 2011 to deliver water for the Farmers Ditch. The alternative considered in the SOR would be an extension of this project to further improve the efficiency of delivering this water by including a short reach of channel to the Farmers headgate located along the Arkansas River channel. Information developed in the South Side feasibility study was used for evaluating this alternative. A second alternative project would be to utilize the Great Eastern on the north side of the river to deliver water directly to the Farmers Ditch and avoid river transit loss above the Farmers headgate.

A third alternative developed to address the Farmers Ditch issue would be a channel improvement project for the Arkansas River. After site visits and consideration of the scope and cost of constructing improvements in the bed of the Arkansas River, the study team identified a project involving construction of a lined low-flow channel adjacent to the river.

The Bear Creek Valley recharge project is an alternative to the recharge projects evaluated in the 2008 Feasibility Study # 3 (Ref.5), which evaluated aquifer recharge using existing ditch facilities to deliver river water for small scale recharge within the ditch service areas. The recharge alternative evaluated for the SOR would supply river water by diversion of high flows in excess of the capacity or water rights of the existing irrigation canals to deliver for aquifer recharge to a natural basin. This would require construction of a new canal.

Both the increase of flow for diversion by the Farmers Ditch with an alternate delivery system and the use of surface water in the South Side Ditch service area would reduce the amount of irrigation pumping from the regional aquifer, by increasing the reliance on surface water. These projects would provide the benefit of reducing groundwater pumping. The managed recharge project would enhance aquifer storage for subsequent use by pumping.

Two other projects were identified initially as part of the SOR scoping process. Study of the potential to improve groundwater quality for one or more of the local municipalities by lining irrigation canals and laterals was recommended by the Advisory Committee as a concept for review during the SOR. After initial review of this concept, it was concluded that the potential disruption of aquifer recharge due to lining may not be offset by the water quality benefit that might be achieved. There was not a strong municipal supply advocate for this study. The concept and benefits that could be obtained are described in this report, but no specific project for implementing this concept was developed.

A project that has been undertaken to replace the Sand Creek flume on the Amazon Canal was also identified during the scoping process. This project is a repair/rehabilitation of a major structure on the largest canal in the study area and was deemed to be beneficial from the standpoint of water savings. The costs and benefits of this project have been previously documented in other reports. The project cost was not updated for this study and the amount of water savings was not estimated for this study.

After the projects for consideration were identified, conceptual designs were developed and costs were estimated for each project. A description of the project objectives and operation has been prepared. Quantities of water savings are provided. This report provides a comparison of costs and water savings expected from each project. Other benefits are also identified. The needs for further investigation of each alternative are also identified in this report.

2.0 Water Supply System

2.1 Arkansas River Conditions

The Arkansas River flows into the State of Kansas from Colorado. The river enters western Kansas in Hamilton County, and flows eastward about 40 miles to the project area in Kearny and Finney Counties. The Project Area is the river located in Kearny and Finney Counties, Kansas between the USGS stream gages near the town of Kendall on the western end and near Garden City on the eastern end, and the service areas of the Associated Ditches that divert from the river in this vicinity. A description of the stream gages and streamflows in recent years is provided below:

<u>Arkansas River near Coolidge</u>

This gage is located on the right bank at the downstream side of the bridge on County Road B, 1.0 mile south of Coolidge, 1.9 miles downstream from the Colorado-Kansas state line, at mile 1,099.3. With reference to the North American Datum of 1927, it is at Latitude 38°01’39”, Longitude 102°00’40” in the NE ¼ NE ¼ NW ¼ of section 26, T.23 S., R.43 W. in Hamilton County, Kansas. The period of record is May to October 1903, March to May 1921, and October 1950 to present. This, along with the Frontier Ditch near Coolidge, comprises the Stateline flow as defined by the Compact. This gage is used for the administration of river flows and John Martin Reservoir Account releases. Average annual stateline flow from 1982 to 2011 was 183,600 ac-ft/yr, ranging from 35,900 in 2003 to 536,600 in 1999. The Stateline flow since the end of the study period for the SOR was actually less than this minimum for both years 2012 and 2013. The 2013 flow totaled 20,100 ac-ft.

<u>Frontier Ditch near Coolidge</u>

This gage is located on the left bank, 0.3 miles east of the Colorado-Kansas state line, 0.5 miles west of Coolidge, and 2.3 miles downstream from the diversion of the Arkansas River. With reference to the North American Datum of 1927, it is at Latitude 38°02’18”, Longitude 102°02’19”, and is in the SW ¼ SE ¼ NE ¼ of section 21, T.23 S., R.43 W. in Hamilton County, Kansas. The period of record is October 1950 to present. This, along with the Arkansas River near Coolidge, comprises the Stateline flow as defined by the Compact. This gage is used for the administration of river and John Martin Reservoir Account releases, as well as for the measurement of two Frontier Ditch water rights.

<u>Arkansas River at Syracuse</u>

This gage is located on the left bank at the downstream side of the bridge on U.S. Highway 27, 0.5 miles south of Syracuse, at mile 1080.9. With reference to the North American Datum of 1927, it is at Latitude 37°57'58", Longitude 101°45'43" in the NW ¼ SE ¼ NW ¼ of section 18, T.24 S., R.40 W. in Hamilton County, Kansas. The period of record is August 1902 to September 1906, published as "near Syracuse", and October 1920 to present. The mean annual flow for 1982 to 2011 was 168,300 ac-ft/yr. It is used by the National Weather Service for flood forecasting, and is also used for the administration of river flows and John Martin Reservoir Account releases.

<u>Arkansas River at Kendall</u>

This gage is located on the left, downstream side of the bridge on County Road Y, 0.25 miles south of Kendall, 6.7 miles from the headgate of the Amazon Ditch Diversion, at mile 1,066.7. With reference to the North American Datum of 1927, it is at Latitude 37°55'48", Longitude 101°32'56" in the SW ¼ SE ¼ of section 25, T.24 S., R.39 W. in Hamilton County, Kansas. The period of record is April 1979 to September 1982, June 2000 to September 2010, and May 2011 to present. It is used for the administration of river flows and John Martin Reservoir Account releases.

Due to the significant lapse in time for the period of record at this gage, streamflows were estimated by comparing streamflows at Kendall to the Syracuse gage, located 14 miles upstream of the Kendall gage, during periods of time where data was available at both gages. A strong correlation between data was identified. Therefore, an equation was developed to calculate the Kendall streamflow from Syracuse gage data for the years from 1983 - 2000. The mean annual flow during 1982 to 2011, including estimated flows, was approximately 158,800 ac-ft/yr.

Amazon Great Eastern Ditch near Lakin

This gage is funded by KDWR with USGS matching funds on an ongoing basis. This gage is used for the administration of river flows and John Martin Reservoir Account releases, as well as for the measurement of Amazon and Great Eastern water rights (two total water rights).

South Side Ditch near Lakin

This gage is funded by KDWR with USGS matching funds. This gage is used for the administration of river flows and John Martin Reservoir Account releases as well as for the measurement of the South Side water rights. This gage has also been used as a mechanism to measure water delivered to the Farmers Ditch through the South Side in several recent years.

Arkansas River at Deerfield

This gage is located on the right, downstream end of the bridge on Main Street, approximately 0.75 miles southwest of Deerfield, at mile 1039.8. With reference to the North American Datum of 1927, it is at Latitude 37°58’11”, Longitude 101°07’42” in the NW ¼ SW ¼ NE ¼ of section 14, T.24 S., R.35 W. in Hamilton County, Kansas. The period of record is October 1998 to September 2010 and July 2011 to present. The mean annual streamflow for 1999 – 2010 was approximately 76,300 ac-ft/yr. It is used for the administration of river flows and John Martin Reservoir Account releases.

Farmer’s Ditch near Deerfield

This gage is funded by KDWR with USGS matching funds. This gage is used for the administration of river flows and John Martin Reservoir Account releases as well as for the measurement of the Farmers’ water right.

Arkansas River at Garden City

This gage is located on the left bank of the downstream side of the bridge on US Highway 83, 0.5 miles south of Garden City, at mile 1,024.2. With reference to the North American Datum of 1927, it is at Latitude 37°57’21”, Longitude 100°52’37” in the NW ¼ SE ¼ NW ¼ of section 19, T.24 S., R.32 W. in Finney County, Kansas. The location is 14 miles downstream of the Farmers Ditch headgate and is an indicator of the streamflow passing out of the study area. The flow at the gage is known to include urban runoff at times. Since the early 1970’s, there has frequently been no streamflow at this location. The period of record is June 1922 to June 1970, July 1970 to September 1986 (flood hydrograph record), and October 1986 to present. The flood hydrograph record for 1970 – 1986 was converted to streamflow for evidence in Kansas v. Colorado, and therefore a record of flow during this interval is available at this location. The mean annual streamflow was 61,100 ac-ft/yr between 1982 and 2011. There has been significant flow past Garden City in 12 of the 30 years to 2011, with effectively no flow during the remaining years. There has been effectively no flow past the gage since 2001. The gage is used for by KDWR and the Associated Ditches for administration of river flows and John Martin Reservoir Account releases.

Table 1 is a summary of annual streamflows at the river gages described above. The flow record for the Arkansas River at Dodge City has been included. This site is 50 miles downstream of Garden City (see **Figure 1**) and reflects the continuing reduction of flow downstream below Garden City for the study period.

2.2 Description of Ditches

Surface water use in the area is by direct diversion from the Arkansas River for irrigation by the Associated Ditches. Water diverted by the canals is used for gravity and sprinkler irrigation on approximately 41,800 acres in recent years. Near Kendall, the river crosses the Bear Creek fault and is in an area of direct connection to the Ogallala Aquifer from that point east. Water diverted for irrigation also recharges the Ogallala aquifer underlying the canal service areas.

The water supply to the canals is documented by the records of historical diversions. A summary of the annual recorded diversions is provided in **Table 2**. Monthly detail is provided in **Appendix B**. Diversions during the period of 1982 – 2011 have averaged 63,800 **ac-ft/yr**, ranging from 8,100 in 2011 to 134,400 ac-ft. in 1986. Descriptions of the individual canals are provided below:

<u>Farmers Ditch/Garden City Ditch</u>

The Farmer's Ditch System is owned and operated by the Finney County Water Users Association (FCWUA). The main ditch is approximately 15 miles long and there are 25 miles of laterals. The FCWUA shareholders have shares that are proportionate to the area of irrigated land. The Farmer's Ditch headgate is located on the Arkansas River east of Deerfield, about one mile downstream of the stream gage at Deerfield and approximately 20 miles downstream of the diversion works for the Amazon and South Side Ditches. Diverted water is conveyed east and the primary distribution system is north of Garden City, Kansas. **Figure 2** shows an overview of the system.

Water is also diverted for the Garden City Ditch by the Farmers Ditch. Although the ditches now share a common headgate, the ditch systems have separate water rights and are independently owned and operated. The headgate of the Garden City Ditch was originally about a mile further downstream. The ditches have a cooperative arrangement involving the use of the headgate of the Farmers Ditch for diversion of Garden City Ditch water rights from the Arkansas River. The Garden City diversions are now delivered to a drop structure located near the Kearny-Finney county line and just upstream of the Farmer's Ditch measuring station. The Garden City Ditch is a system comprised of approximately 7.5 miles of irrigation ditches.

The two ditches carry water to irrigate land to the west and northwest of Garden City. The service area of the Garden City Ditch formerly included cropland that has been converted to other uses in western Garden City. The amount of water available for use in recent years has been variable due to the relatively small flow in the river.

The historical diversions since 1982 are summarized in **Table 2** and monthly values are provided in **Appendix B**. The average annual diversion, excluding the Garden City Ditch, was 12,300 ac-ft/yr. The Garden City Ditch diversions averaged 1,700 ac-ft/yr.

In recent years, (2011 - 2013) the Farmer's and Garden City Ditches received little or no surface water because of low flows in the river at the Farmers headgate. An Alternate Delivery System (ADS) would allow the Farmer's and Garden City ditches to receive a greater share of surface water supplies than otherwise could be delivered by the Arkansas River during certain circumstances (low river flow and depleted alluvial aquifer conditions). When conditions prevent surface water deliveries to the Farmer's Ditch, surface water is redistributed upstream and groundwater recharge in the service area is lost when surface water is not applied.

South Side Ditch

The South Side Ditch diverts four miles further downstream of the Amazon headgate and supplies approximately 10,000 acres on the south side of the river. The main canal is approximately 19 miles long. Much of the land served by this system has been converted to center pivot sprinkler system, and groundwater subsequently became the primary source of supply. The capacity of this canal is 200 cfs at the upper end of the ditch. Diversions have averaged 11,000 ac-ft/yr since 1982. A feasibility study for improvements on this ditch described the costs and benefits of lining the ditch. A new return channel to the river was constructed in 2010 to start facilitation of an ADS for the Farmers Ditch. The service area is primarily sandy soils, with higher infiltration rates than under the canal systems on the north side of the river. Also, depths to groundwater are shallower in this area.

Amazon Canal

Downstream of the Frontier Ditch the Amazon Ditch is the furthest upstream of the Associated Ditches. The headgate of the Amazon Ditch is in central Kearny County as shown on **Figure 2**. The canal runs in a generally northeasterly direction to irrigate approximately 16,000 acres north of Deerfield and in western Finney County. The ditch is operated by the Kearny County Farmers Irrigation Association. The Amazon Ditch currently diverts the largest quantity of water from the Arkansas River in Kansas. The Amazon Headgate Project, completed in 2012, replaced the vintage 1880's diversion structure with new gates and controllers. Water savings were estimated at 2,000 acre-feet of water per year, primarily through reduced leakage around the 12 original slide gates. The anticipated addition of controllers for remote operation of the four new radial gates is expected to improve management and efficiency of the diversion works.

The average annual diversions for the Amazon have been 22,100 ac-ft/yr, excluding diversions for the Great Eastern and Lake McKinney. The combined diversions averaged 39,000 ac-ft/yr.

Great Eastern

The Great Eastern Canal system is owned and operated by the Garden City Company (GCC). It originally diverted from the Arkansas River at the location of the South Side diversion works. An agreement was entered in 1952 between GCC and the Kearny County Farmers Irrigation

Association (Kearny County Farmers), owners of the Amazon Canal after which use of the original Great Eastern Canal from the Arkansas River was discontinued and diversions were made through the Amazon. The agreement provides that Great Eastern's water can be taken through the Amazon to Lake McKinney, subject to Kearny County Farmers having the right to supply the Amazon lands with direct irrigation water first, with Great Eastern taking water as capacity is available. After the implementation of this agreement, a portion of the canal was abandoned and the Great Eastern Canal began to divert water at the outlet of Lake McKinney. The agreement also provided that the Amazon Canal capacity would be enlarged to 600 cfs to carry the diversions for both systems. The diversion records indicate that the actual capacity of the Amazon Canal may not have been enlarged to this amount.

Operation of the Great Eastern in this manner resulted in system inefficiencies related to delivery of the water through the reservoir. Water was lost to evaporation and seepage while it was stored in or delivered through the reservoir. In addition, when the reservoir was empty, large losses were experienced while delivering water to the outlet through the dry lake bed. As a result, several alternative delivery options were investigated by the GCC and the Kansas Water Office, and in 2010, a bypass channel was constructed from the Amazon Canal near the Lake McKinney inlet, around the east side of Lake McKinney, directly to the Great Eastern below the lake outlet works. The bypass channel is used during periods of low or no storage in the reservoir to deliver water directly to the Great Eastern. When there is significant storage in place, operations are expected to be essentially the same as with the historical post-agreement configuration, with delivery through the lake. Because of the recent completion of this project, there has been limited operational experience with the bypass channel in place. It is expected that deliveries from the Amazon will be more efficient and timely if not passed through the lake bed, and that there will be better coordination with operations of the Amazon Canal to improve flexibility in managing diversions between the two companies.

The capacity of the Great Eastern Canal below the McKinney outlet is estimated to be 200 to 300 cfs, (SWE/WWE, 2005), depending on the freeboard maintained to provide a factor of safety to accommodate runoff into the canal. This capacity estimate is based on information from the GCC. The acreage served with surface water has ranged from 10,000 to 12,000 acres based on information from the GCC. The canal extends for a distance of approximately 19 miles from the dam to the north and east. Most of the lands served are owned by the GCC, which owns more than 90% of the water right in the Great Eastern. The diversions at the Amazon Canal are allocated between the Amazon and Great Eastern water rights by the companies and KDWR. Any limitations on Great Eastern diversions attributable to the agreement are reflected in the records. **Table 2** provides historical Great Eastern and Amazon diversions. Historical diversions for the Great Eastern averaged 17,800 ac-ft/yr. from 1982 to 2007, ranging from 4,400 in 2007 to 41,900 in 1986. Diversions during the five-month period months of November through March have averaged approximately 4,200 ac-ft, or approximately 25% of the total annual diversions. Records since 2006 are only available for the combined Great Eastern and Amazon diversions.

Annual diversions are plotted in **Figures 3a – 3f**. Average annual diversions have totaled approximately 63,800 ac-ft/yr over the study period, as shown on **Figure 3f**.

2.3 Water Supply

2.3.1 Surface Water Allocation

The canal diversions are regulated by the Kansas Department of Agriculture, Division of Water Resources (KDWR). The source of supply for the canals is primarily flow in the Arkansas River at the Stateline. The river is largely managed by releases from John Martin Reservoir (JMR) pursuant to the provisions of the Arkansas River Compact. Each State has a share of the reservoir supply. The Kansas water users and KDWR have control over Kansas' share of water in John Martin Reservoir, which can be called for as needed for direct irrigation, normally during the irrigation season from April through October. The canal managers request reservoir releases based on available storage, weather conditions and river conditions. The objective is to maximize the benefit of available storage for crop production. Release rates are generally in the range of 400 to 800 cfs, at the Stateline.

During times when water is being released from JMR, water is not stored in Lake McKinney. At other times, water can be diverted for irrigation or for storage in Lake McKinney if it is not needed by the canals for direct irrigation.

The distribution of the Arkansas River surface water supply among the ditches in Kansas is governed by: (1) a series of federal court decrees predating the Compact, (2) *Rules and Regulations Governing the Rotation, Diversions and Use of the Water for Irrigation Purposes from the Arkansas River by Irrigation Companies in Kearny and Finney Counties, Kansas* (Rotation Rules) and (3) informal "river run" agreement. The "Rotation Rules" are subject to annual agreement which is intended to be compliant with and provide clarification to the federal court decrees. The Frontier Ditch has been included in the distribution of the available supply by an Order of the Chief Engineer on Vested Right, HM-026 (Ft Aubrey). Under the various rules and agreements, there are a number of ways that the available surface water supply can be distributed. Most recently, the distribution has been accomplished through a consensus process, whereby the ditches agree to the distribution based on prevailing river conditions as documented by streamflows and ditch diversions. The river condition can be determined by the flow losses between each streamgage. The immediate availability of both the instantaneous and cumulative ditch diversion records has greatly aided in this consensus process.

The rotation schedule and agreed upon water usage from the Rotation Rules are as summarized in **Table 2.1**.

Table 2.1
Summary of Rotation and Water Usage

Order of Rotation	Name of Ditch Company	Decreed Rotation Rights (acre-ft)	Maximum Annual Volume (acre-ft)	Maximum Authorized Diversion Rate (cfs)
1	Amazon Ditch (KE-79)	3000	31,000	200
2	South Side Ditch (KE-78)	3000	20,000	200
3	Great Eastern Ditch (KE-77)	5312.5	60,000	300
4	Farmer's Ditch (KE-76)	3937.5	20,000	250
5	Garden City Ditch (FI-217)	500	4,000	80

There are two general river administration modes: (1) natural river flows and (2) John Martin Reservoir account releases.

Natural River Flows

During administration of natural river flows, the available supply is distributed among the six irrigation ditches. The basis for distribution depends on the amount of water available at each headgate and the overall river condition. During dry conditions, the river is diverted by one or more ditches until the available supply is used. How long each ditch diverts can be based on the amount diverted, among other things. During wet river conditions, although all of the ditches may be able to divert, the diversion rate is again governed by the available surface water supplies.

John Martin Reservoir Account Releases

For the administration of JMR account releases for the benefit of Kansas ditches, the ditches have also used consensus agreement to distribute the available surface water supply. The river condition determines: (1) which account to call on, Offset, Section II, or both; (2) the release rate; (3) the distribution between the Ditches; and (4) whether the South Side Ditch should be utilized to deliver water to the Farmers and Garden City ditches. Information about the location and magnitude of river losses provides information on how the water is expected to move through the system in Kansas from the Stateline to the Farmers headgate. This information is used by the Associated Ditches to adjust the headgate demands to accommodate the available supply and river conditions. Since the river flow can change hour-to-hour, the streamflow and diversions are monitored closely in an attempt to provide an equitable distribution of the available supply.

During the irrigation season, the canals divert all available water in the river, except during high flow or reservoir spill conditions. Some diversions are made in the off-season for storage in Lake McKinney. Winter flows at the Stateline tend to flow past Lakin, but do not normally reach Garden City.

Spill events at JMR are infrequent and there may be long intervals between spill events. Any plan to utilize spill water should take into account the expected frequency of events. During past periods of spill, streamflows have been restored throughout the system downstream to Kinsley and significant amounts of recharge have also occurred downstream. Some effect on recharge amounts would result if new diversions were made during periods of high flow at Kendall.

2.3.2 Groundwater Pumping and Water Levels

The primary source of irrigation supply in the study area is groundwater pumped from the High Plains Aquifer (Ogallala Aquifer). For this study, pumping and water level data were compiled for the study area within the ditch service areas. These data provide documentation of the changing aquifer storage status and the level and variability of pumping. As noted in previous investigations, total pumping in the two-county area is significantly greater than within the canal service areas. The 2005 study documented 400,000 ac-ft/yr of pumping in the two counties during the 1990's. (Ref. 2, pg. 9). This pumping was applied to a total irrigated area of 320,000 acres.

The pumping within the ditch service areas was tabulated for this investigation from water use records maintained by the State of Kansas. The period of 1990 – 2012 was included. **Figures 5c – 5g** illustrate the pumping by each of the five ditch service areas. Pumping averaged **78,000 ac-ft/yr**, ranging from a high of 122,000 in 1991 to 56,000 in 2005. The records are available on an individual well basis and also record the irrigated acres. The total acreage averaged **67,000 acres**, ranging from 60,000 acres in 2012 to 74,000 acres in 2002. Pumping application depths overall averaged about **14 inches**, reaching 20 inches in dry years, such as 2011 and 2012. Pumping amounts and depths are illustrated in **Figure 5**. **Figure 5a** shows the combined annual pumping. **Figure 5b** shows the pumping expressed in inches of application. **Figures 5c – 5g** show the annual pumping by ditch service area.

The acreage irrigated in the canal service areas exceeds the acreage receiving surface water in a normal year, since some land was developed for groundwater irrigation or converted to only groundwater at some point in the past. The pumping data demonstrate that groundwater withdrawal has declined since about 2002. This trend is due to efficiency improvements and conservation. Annual pumping varies with precipitation, as illustrated by the varying pumping depths. Pumping also varies due to the available surface water supply delivered by the ditches. In several recent years (2011 - 2013) there has been very little surface water supply. Since most of the land irrigated by surface water also has access to groundwater, the enhancement of surface water supply in the study area has the effect of reducing the draft on the aquifer.

Water level data were also compiled from the period of 1997 – 2012. The data are reflective of winter static water levels. Data are referenced to depth to water from approximate ground surfaces applicable for each of the ditch service areas. **Figure 4b** is a plot of the depths to groundwater for each of the service areas. Water level data indicate declines in static water levels over the entire period, with higher rates of decline in the recent dry years since 2009. The depths to water in the South Side Ditch service area are less than for the ditches on the north side of the river. Water level changes between 2000 and 2012 on the north side of the river ranged from 38 feet in the Amazon service area to, 60 feet in the Farmers service area, and to almost 80 feet in the Great Eastern service area. These water level changes are derived by taking averages for a few selected points in each ditch service area, and should be considered approximate to illustrate the changes in depth to groundwater over the period. These data were acquired from the Kansas Geological Survey website.

Data from several observation wells which had been previously reviewed and used to describe water level conditions in the study area were extended from the same source of data. Data from these wells were documented in the KGS report of 2002 (Ref. 1). These data show similar changes to the water levels in the Amazon and Great Eastern Ditch service areas. Two of the wells show water level declines of about 60 feet from 2000 to 2012. **Figure 4a** displays the updated information for these wells.

<u>Pumping Costs</u>

Information about the costs of pumping irrigation water was not provided for this investigation. Information compiled from a 1998 investigation of damages resulting from compact violations through 1996 was reviewed and used to make an approximate estimate of pumping costs (Ref. 9). The two primary variables for cost of pumping in this region are the groundwater levels and cost of natural gas. Due to the deep and variable water levels in this area, this factor is a significant component of cost. Current natural gas prices are not readily available. Information available for 1996 conditions indicated a “representative price” of natural gas at $4.61 per mcf.

An estimate of unit pumping cost ($ per acre-foot per foot of pumping head) for fuel, assuming the 1996 fuel cost, was determined to be $0.17/ac-ft/ft. This value includes a number of assumptions about well and pump efficiency. Other components of variable cost, such as labor and maintenance, were determined to be a small component of variable pumping cost.

Assuming that the pumping head for center pivot sprinklers averages approximately 115 feet (50 psi), and that the pumping lift is 169 feet (Farmers Ditch area, 2012), the total pumping head would be 284 feet. This would result in fuel cost for pumping of ($ 0.17/ac-ft/ft x 284) = $48/ac-ft. Fuel cost for pumping for gravity application would be ($0.17/ac-ft/ft x 169) = $29/ac-ft. The difference between using surface water and groundwater would be attributable to the pumping lift of 169 feet, resulting in a difference of $29/ac-ft. The estimated recent pumping lift in the South Side service area is 100 feet. This results in a fuel cost of $37/ac-ft for pumping groundwater to a sprinkler and $20/ac-ft if the pumping lift is avoided by using surface water. The difference, or savings would be $17/ac-ft under the South Side Ditch.

This estimate could be improved by using the current price for natural gas, or the current level of pumping costs per acre-foot that could be documented by water users.

3.0 Water Supply and Management Issues

3.1 Prior Studies

Basin Management Plan

The *Kansas Water Plan* (2009, Ref.12) is used by the State of Kansas to coordinate the management, conservation and development of the water resources of the state. It contains recommendations on how the state can best achieve the proper use and control of water resources. The Kansas Water Office is responsible for developing the *Kansas Water Plan*. The Kansas Water Authority approved the Update of the 2009 *Kansas Water Plan* on January 29, 2009.The Water plan includes twelve river basin plans, including one for the Upper Arkansas River.

An enforcement action brought by Kansas in the United States Supreme Court determined that depletions to Kansas' allocation had occurred in violation of the compact, which resulted in an award of damages to the State of Kansas. The Kansas legislature adopted K.S.A. 82a 1801 - 1803, which establishes the criteria for allocation of funds obtained in Kansas v. Colorado for water conservation projects (1803). This Conservation Fund is available for the area in Upper Arkansas River Basin directly impacted by the provisions of the Arkansas River Compact. A steering committee consisting of local water interests and state water officials was established to identify projects that would qualify for use of this fund. The State of Kansas has identified water management needs in the Upper Arkansas River Basin, through the Basin Management process implemented through the Kansas Water Office (KWO). A basin management plan has been developed.

Upper Arkansas River Conservation Project Reconnaissance Study

In 2005, Spronk Water Engineers and Wright Water Engineers (SWE/WWE) prepared a report for the KWO "Upper Arkansas River Conservation Project Reconnaissance Study" to investigate the preliminary feasibility of the alternative projects that were identified by local water users. Subsequent to the development of the Basin Management Plan, the Arkansas River Litigation Fund Steering Committee was formed to provide local input in the identification of management and conservation needs. This committee, operating in coordination with the Kansas Water Office, refined the identification of water management needs in the area and developed a list of alternative projects. The SWE/WWE report recommended further study of an alternate means of delivery to the Farmers Ditch, potential for restoration of some capacity in Lake McKinney, bypass of the Great Eastern Canal around Lake McKinney, managed aquifer recharge, channel modifications, and management strategies for water rights retirement and Kansas water stored in JMR in Colorado. Water management improvement opportunities identified in the 2005 SWE/WWE report included:

Transit Loss of River Flows Delivered to Downstream Canals

The Farmers and Garden City Ditch divert river flows near Deerfield, approximately 18 miles downstream (east) of the diversions for the other canals near Kendall. At times, the channel losses in this reach can be quite high, requiring large flows past Syracuse to satisfy the demands of the Farmers and Garden City water rights. Because all of the canals are entitled to have their water rights filled proportionately, the channel losses that occur between Syracuse and Deerfield reduce the supply available to all. More efficient conveyance of these flows could be achieved by using the existing canal systems to deliver water to these downstream water rights. Two alternatives have been identified for investigation; the southside and northside alternative delivery systems. By restoring the capacity of either the Southside Ditch or the Great Eastern Ditch, and coordinating operations, more efficient deliveries could result.

River Flows not Diverted by the Canals

Streamflow that is not presently diverted occurs during periods of high streamflow or beyond the irrigation season. It would be beneficial to develop capacity to divert this water for recharge of the Ogallala aquifer. If this capacity were available, it may also prove beneficial to change the use of some of the existing surface water rights to be used for recharge. Diversions and recharge of river flows in a managed operation would provide the ability to control the location and water quality effects of recharge.

Hydrologic and Water Rights Investigation

The alternatives for recharge and additional storage will require studies of water supply. The feasibility studies should include operational studies, evaluations of water rights and *identification of operational and administrative issues. For recharge projects, ground water modeling should be developed to quantify impacts to the aquifer, both in terms of water quality, water levels and ground water flow. The surface water study should identify constraints for existing water rights and clearly define issues related to changing the use of existing water rights or developing further water rights for recharge projects. The operational studies would quantity the yield expected for recharge or restored reservoir capacity. Groundwater modeling would likely be done in cooperation with the KGS, using previous modeling as a basis for evaluation of the alternatives being considered. The costs for these studies are estimated to be $70,000 to $90,000 for surface water and water rights evaluations. The cost for groundwater modeling is assumed to be in addition to participation by the KGS. Estimated costs would range from $140,000 to $160,000.*

River Corridor Conditions

The condition of the river channel between the Stateline and Garden City has been identified as a potential need for management. Riparian vegetation is extensive and results in water loss due to consumption by salt cedar (Tamarisk). Activities are currently in progress to identify the conditions and determine potential benefits of control or eradication of salt cedar. River channel degradation in the vicinity of Garden City has also been identified as a condition that could be improved. Placement of grade control structures in this reach of the river would be beneficial.

Lake McKinney Feasibility Study

In November 2007, SWE and WWE, together with Stantec Consulting, Inc., Michael W West & Associates, Inc. and Bruce M McEnroe, prepared a report "Lake McKinney Feasibility Study" for the KWO to further evaluate the feasibility of the improvements to the lake that were recommended in the 2005 report. The investigation focused on two options: increasing the lake capacity from 3,300 af to 7,900 af by raising the existing dikes and making improvements to the dam and outlet works, and constructing a bypass channel around the Lake to convey irrigation water for the Great Eastern Canal directly from the Amazon Canal instead of routing the water through the lake. In 2010, some material was removed from the lake bed, new outlet works were installed, and the dikes were raised in order to increase the reservoir capacity. The study included an analysis of additional water that could be available for storage beyond historical diversions for storage in the restored lake capacity, based on river flow data.

Feasibility Study No. 1: South Side Ditch and Southern Alternate Delivery System

In October 2007, Burns & McDonnell Engineering Company, Inc. (BMEC) prepared a report for the KWO "Water Conservation Project Fund, Arkansas River Corridor, Feasibility Study No. 1: South Side Ditch" to investigate the feasibility of creating the South Side Alternate Delivery System (ADS) that had been described in the 2005 SWE/WWE report. The study was funded by the Water Conservation Projects Fund Reserve Account. The Southside ADS proposed to carry water intended for the Farmers Ditch and the Garden City Ditch through the South Side Ditch, and then return it to the Arkansas River channel upstream of the Farmers headgate. The ADS would be used when transit losses in the river are high. The study also investigated options for lining of various portions of the South Side Ditch to reduce transit losses in the ditch. Preliminary engineering design and construction cost estimates were completed in early 2009. In 2010, "Alternative 2" of the ADS as described in the BMEC report was constructed, and portions of the ditch were lined with lake bed material salvaged from the concurrent project to increase the capacity of Lake McKinney.

Feasibility Study No. 3: Enhanced Aquifer Recharge from Arkansas River Flows

The Water Conservation Project Fund - Arkansas River Corridor Feasibility Study No. 3 was completed for the KWO in August, 2008. The study identified and evaluated a number of recharge sites that could receive water from the existing canals. The recharge operation would be integrated into the ditch operations, using water that is derived from the water rights of the ditches or potentially additional water rights specifically appropriated for recharge. A number of alternatives were considered. Alternatives included various sites and facilities, including sand pits and constructed recharge basins, canal recharge, Lake McKinney and directed recharge to the river alluvium downstream of Garden City.

The study provided cost estimates and recharge capacity for a number of sites. They were then compared for benefits and costs and a priority list developed. The study included some modeling of the recharge benefits from a number of the sites. To date, none of the recharge site have been developed for managed recharge. The study identified a number of issues that would need to be addressed or investigated further.

The study concluded that flows are available for diversion at a rate of 15 cfs at least 50% of the time and 100 cfs 25% of the time. These rates and frequencies were computed for the 1980 - 2005 period of record of streamflow, and would be above historical diversions and river channel infiltration between the Stateline and Garden City.

The water available for diversion to managed recharge sites would be expected to recharge the river alluvium and High Plains Aquifer through seepage from the river bed downstream of the diversion points if left in the river. The recharge program would allow water levels to be enhanced at more beneficial locations and avoid some consumptive transit loss in the river bed. The study identified a number of alternative sites and ranked them based on physical characteristics, cost, benefit and other operational considerations. The study did not propose a plan to optimize the number of sites to be developed based on available supply, costs and benefits. The flow rates available for diversion would include a large range, up to the diversion capacities of the existing structures, but as the diversion rate is increased, the duration of available flows would decrease.

The study makes note of two compact provisions that may affect diversions for recharge:

- *Article V.H. provides that the ditch diversion rights in Kansas shall not be increased beyond present rights without findings by the Administration that no depletions or adverse effect will result.*

- *Article V.E.2 requires water releases from JMR to be applied promptly to beneficial use unless the Administration approves storage.*

The study included evaluation of a small-scale version of the Bear Creek Valley site that is also included in this investigation. The study noted the existence of a clay aquitard at depths of 40 to 106 feet, based on several nearby well logs and noted:

Recharge will be primarily to the alluvial aquifer. Because of higher potentiometric heads in the alluvial aquifer, water in the upper aquifer will slowly migrate to the underlying High Plains aquifer by natural seepage through and around clay layers and through old wells that were gravel-packed or completed in both aquifers. However, movement of the recharge water to the High Plains aquifer is expected to be relatively slow.

3.2 River Transit Losses

One of the purposes of the SOR was to quantify streamflow conditions and losses in the Arkansas River between Kendall and the Farmers Ditch headgate. Streamflow records have been compiled and analyzed to quantify losses under the range of flow conditions. Gages at Kendall, Deerfield and Garden City were used. A study period of 2000 – 2011 was used based on availability of data at the Kendall and Deerfield streamflow gages. The stream losses from the Kendall to Garden City gages were estimated and plotted against the inflow of the reach. **Figures 6a – 6c** are plots of the loss data. A relationship of loss to inflow was derived.

Daily streamflows were used to estimate losses. The mass balance equation used to quantify loss is gage inflow minus gage outflow, including diversions from the reach by the canals. Losses were quantified in the two reaches above and below Deerfield. The results were summarized by winter (November – March) and summer (April – October) season.

Losses are expressed as net gains/losses between the gages, and in terms of percentage of reach inflow and unit loss rates (cfs/mile). The results of the loss analysis are provided in **Table 3**. Graphs of loss by reach and flow rate inflow to the reach are shown on **Figures 6a – 6c**. Detailed results are presented in **Appendix C**.

In summary, several conclusions have been made based on this analysis:

- Losses, expressed on a per mile basis, are higher in the river reach below Deerfield.

- The average rate of loss varies with inflow; at low flows (< 100 cfs) losses averaged less that 2 cfs/mile above Deerfield and 2.5 to 3.5 cfs/mile below Deerfield. For 200 cfs, the loss rate is increased to 2.6 cfs/mile above Deerfield and 5.4 cfs/mi below Deerfield.

- Approximately half of the Kendall inflow is lost above Deerfield at 200 cfs of inflow.

- When flow is less than 100 cfs at Kendall, much of the water is lost in transit to Deerfield and the Farmers headgate.

- During years of low water supply, flow passing the upper headgates would need to be 350 cfs in order to provide 200 cfs at the Farmers headgate.

- There was no flow at the Deerfield gage 38% of the time during the irrigation season over this period.

- There is normally no flow at the Garden City gage during the irrigation season, but flow returns again in most winters.

The analysis provides the documentation of a losing channel and the challenges to deliver water in the Arkansas River to the Farmers Ditch under conditions prevailing throughout the 2000 – 2011 period. The results of the quantification were used to estimate the benefit that could potentially be achieved by providing a lined low-flow channel for a portion of this reach of the river above the Farmers Ditch headgate.

3.3 Canal Efficiency

Canal delivery efficiencies were estimated for two canals to evaluate the potential benefits of alternative deliveries to the Farmers Ditch involving the South Side Ditch and the Great Eastern Ditch. Canal loss rates were not investigated or estimated for the Farmers Ditch, since the alternatives ultimately identified did not include improvements to the Farmers Ditch.

<u>South Side Ditch</u>

The BMEC feasibility study estimated seepage rates of 33.7 cfs from the existing canal. This equates to 3,360 ac-ft/yr of loss over the study period of 1980 – 2005 for baseline (existing) conditions, a loss rate of 32%. Earlier estimates of loss for the ditches were based on a rate of 1% per mile, for evidence developed in Kansas v. Colorado damages trial. This resulted in an estimate of 23% for South Side ditch loss. Neither of these estimates is based on actual seepage measurements or delivery records within the ditch. The feasibility study did include analysis of soils characteristics and discussions with ditch company officials. Therefore, it is considered to be a more realistic estimate. For purposes of the SOR, we assumed loss rates for delivery of water through the South Side Ditch would range between 23% to 32% for existing conditions. Improvements to the ditch described in the feasibility study would improve the delivery efficiency of the South Side Ditch.

<u>Great Eastern Ditch</u>

Due to the size of the Great Eastern Ditch and its configuration with internal reservoir storage, it is not known whether ADS deliveries would be made at times when the Great Eastern was not otherwise operational or would be conducted jointly. If operated separately, deliveries would be based on actual amount reaching the delivery point; if not, a carriage assessment would be required. Estimates previously made of loss rates in the Great Eastern were adopted for either mode of operation in the SOR, because no loss measurements were available or collected as part of the SOR. The losses would include those incurred in both the Amazon and Great Eastern Canals. Estimates had been previously made for two studies; the damages calculations in Kansas v. Colorado (1998, Ref. 13) and in the Lake McKinney feasibility study (2007, Ref.4). The 1998 study assumed loss rates of 27% on the Amazon and 20% in the Great Eastern, excluding losses incurred for delivery through Lake McKinney, for a total loss rate of 47%. The 2007 study assumed a 15% canal loss for the Amazon and 20% for the Great Eastern, for a total loss rate of 35%. For this investigation, and in the absence of more detailed records or measurements, a range of 35% to 47% was assumed as the representative loss rate for ADS deliveries through the Great Eastern system.

3.4 Conceptual Efficiency Improvements

The conceptual efficiency improvement alternatives included in the SOR were developed to achieve specific efficiency goals. The increased use of river water would reduce the draft on the regional aquifer by reducing the amount of pumping that is necessary in the South Side and Farmers Ditch service areas.

The Farmers Ditch diverts irrigation supply for the lands under this ditch and for the service area of the Garden City Ditch. During periods of low flow, there is significant loss of water in the river channel between Kendall and the Farmers diversion. Three alternative projects have been identified to address this situation, as alternate delivery systems (ADS). These include the Southside ADS, the Northside ADS and a river flow restoration alternative in the reach between the South Side return channel and the Farmers headgate, which is a river reach that experiences very high loss rates.

Potential water savings for the ADS alternatives were estimated by comparing the expected delivery efficiencies of the ADS alternatives to actual historical diversions at the Farmers Ditch. Conveyance loss characteristics within the two canal systems have been estimated from information provided by the water users and previous investigations, as described in Section 3.3.

Implementation of the South Side sprinkler pits would increase reliance on river flows in this service area and would reduce the amount of pumping that occurs in the service area.

The implementation of a managed groundwater recharge project would serve to lengthen the life of the aquifer in the affected area and reduce pumping lifts.

4.0 Overview of Potential Water Efficiency Projects

The potential water efficiency projects have been formulated at the conceptual level and are described following a consistent format, as follows:

- Description of the structural and operational features of the project;
- Benefits of the project, primarily in terms of enhanced water supplies, improved efficiencies and potential renewable energy production;
- Costs of implementing and operating the project;
- Additional information that is needed to further evaluate costs and benefits;
- Potential implementation obstacles that will need to be overcome; and
- Potential alternatives to the project that should be considered and explored.

Initial ideas for efficiency improvements were identified in several prior studies and by the GMD3 Board of Directors and staff, with support from the consulting team. These ideas included:

Projects 1 and 5: Alternate Delivery Systems for the Northside and Southside Ditches

The Northside and Southside Alternate Delivery Systems would utilize existing irrigation ditches on the north or south side of the river, respectively, to convey river flows to the Farmers and Garden City Ditch head-gates, thereby avoiding river transit losses. The amount of river losses avoided would depend on the configuration of the modified delivery systems. The two alternate delivery systems are mutually exclusive.

The amount of divertible flow in the Arkansas River at the Farmers Ditch headgate is often substantially reduced by river transit losses in the reaches between the headgates of the Amazon and South Side Ditches and the Farmers. Under most flow conditions, losses in this reach of the river are significant, due to evaporation, evapotranspiration, and seepage into the river alluvium. This is a particular concern in low-flow years. River transit losses are documented in a number of studies and reports.

Projects 1A, 1B and 5 would reduce current river transit losses and increase the surface water available to irrigators on the Farmer's Ditch, thereby improving overall system efficiency within GMD3. Only one of these projects would be selected for implementation. Selection of a preferred alternative would be based on future more-detailed studies that would be performed at the feasibility level.

Both the Northside and Southside alternate delivery alternatives will require the ditches upstream of the new interconnections to be upgraded in terms of their capacities. The amount of upgrading required needs to be determined. However, the study by BMEC (2007, Ref. 3) provides an indication of the potential scope and cost of these types of ditch capacity upgrades.

Project 1: Provide a Northside Delivery System for the Farmers Ditch (Northside Alternate Delivery).

The Farmers Ditch currently has two options to receive water, the first being to take the river water that reaches this headgate, and the second being to use the South Side Ditch to receive deliveries of low flows. River flows experience significant transit loss. The South Side Ditch does not have the required capacity to carry high flows, and there are high losses between the South Side return near Deerfield and the Farmers Ditch Headgate. A Northside delivery system would enable the Farmers Ditch to use the Great Eastern Ditch to convey water past the river reach subject to high loss rates. This project would require construction of a conveyance facility connecting the eastern end of the Great Eastern Ditch to the Farmers Ditch at a location downstream of the Farmers Headgate.

Project 2: River Flow Restoration

Several of water users desire to know if it could be possible to restore flow to the river on a more regular basis and whether this restored flow would lead to reduced losses when water needs to be used for irrigation. SWE has analyzed historical flow and losses in the Arkansas River channel at various times of the year and comparing losses in a wet channel to those in a dry channel. A concept involving "lining the river channel" between the South Side Ditch return flow channel and the Farmer's Ditch headgate has been suggested as a way to reduce transit losses. However, this option is expected to involve major environmental, construction and maintenance issues and is not considered to be practical. In this same reach, however, it may be possible to consider a lined flow-bypass channel that would convey irrigation water around the “bypass reach” of the river to avoid transit losses. Some minimum flow would need to be maintained in the river channel for environmental purposes.

Project 3: Bear Creek Valley Recharge Project and Flood Mitigation Project

This project concept envisions harvesting high flows from the Arkansas River and diverting them into Bear Valley for recharge of the aquifer. GMD3 currently sees either a recharge benefit or a use made of all water in the Arkansas River, as long as that water does not pass beyond the downstream boundary of GMD3.

Project 4: Small Hydroelectric Facilities

GMD3 is interested in assessing the general feasibility of installing small hydro facilities along the ditch system. There is a nominal 11-foot drop in the Frontier Ditch wasteway return to the river. There would also be a drop of nearly 20 feet with one of the North Side delivery systems for the Farmers Ditch. One other hydro site, with about 4 feet of drop has been identified by GMD3 on the South Side Ditch.

Project 5: Conveyance from South Side Ditch Return to the Farmers Ditch Headgate (Southside Alternate Delivery)

Conveying water in ditch or a pipeline from the location of the South Side Return to the river directly above the Farmers Ditch would reduce losses that currently occur in conveying water in the river. This concept is essentially the same as Alternative 1, except it is located on the south side of the river.

Figure 7 is a map showing the location and layout of the various alternatives included in this study to provide an alternative delivery to the Farmers Ditch headgate. Projects 1,2 and 5 are displayed. As indicated, the delivery point from the Great Eastern bypass alternate 1B would be located some distance down the ditch. The other alternatives would deliver water to the headgate of the ditch.

Project 6: Lining of Ditches near Public Water Supplies

The water in the river channel is very poor quality and infiltration in the ditch channels near municipal well fields has caused contamination of the water supply of the cities of Lakin and Deerfield. An evaluation could be made of the cost, and effectiveness, of lining portions of these ditches located near the well fields to reduce seepage and prevent the degradation of drinking water quality. However, further study of this option is not planned at this time, based on consultation with GMD3 staff.

Project 7: Amazon Flume Upgrade

The Amazon Sand Creek Flume is no longer structurally stable and it is expected to be replaced. There will be water savings associated with building a new stable structure with fewer losses through cracks and leaks. The main goal of this project is maintaining water deliveries and not improving water efficiency. Furthermore, this alternative is already being implemented and is not considered in this report.

Project 8: Southside Ditch Sprinkler Supply Pits

This concept involves additional development of small-scale on-farm regulating structures that would store surface water when available for use by one or more center pivots. These pits would be lined and a pumping facility and distribution system would be required.

5.0 Project Descriptions and Analysis

5.1 South Side Ditch Alternate Delivery Project

The Southside alternate delivery system (ADS) would utilize the South Side Ditch to carry water to the river return located at the end of the ditch. This clay-lined channel was constructed in 2010 with the intention of providing an efficient conveyance back to the river to deliver water through the South Side for the Farmers Ditch. The return has been operated in two years since construction. The alternative developed in this study is to provide a channel along the river from the end of the return channel approximately 4,400 feet to the Farmers Ditch diversion works. The channel was assumed to be unlined based on available topographic data from LIDAR surveys, a pipeline was not considered to be feasible for the Southside ADS.

The characteristics of the South Side Ditch system were documented in the report Feasibility Study No. 1 South Side Ditch, prepared for the Kansas Water Office in 2007 (Ref. 3). This study determined the capacity of the system and provided estimates of the efficiency of delivering water through the ditch to the river return. Cost estimates for several different methods of lining the ditch were also developed. Findings of the study included:

- The capacity ranges from 200 cfs at the upper end to less than 100 cfs near the lower end.
- Ditch seepage was estimated to occur at a rate of 34 cfs when operating under normal conditions.
- The cost to line the ditch from end to end was estimated to range from approximately $6 million to $20 million, depending upon the lining material.
- An ADS alternative for the Farmers Ditch would require some upgrading of the ditch capacity.
- The southern ADS operation could be integrated into the South Side Ditch operation because most of the users in the South Side service area have converted to groundwater use, not taking delivery of surface water from the ditch.
- The report noted that the transit losses for the current condition of the South Side Ditch could exceed losses in the Arkansas River between the South Side and Farmers diversion structures due to the sandy soil in the service area.

The South Side Ditch has an estimated current capacity near the tail end of the ditch of 130 - 150 cfs. This information was obtained from the Feasibility Study No. 1 and confirmed by the manager of the ditch. Assuming that deliveries for the Farmers Ditch would be rotated such that they would not be concurrent with deliveries for the South Side users, diversions for the Farmers Ditch water users could occur at rates up to the 130 – 150 cfs capacity range. At other times, diversions could occur concurrently with Southside diversions at lower rates. Except for the return channel, the ditch lining improvements evaluated in that study have not been completed.

The benefits of the ADS alternatives were estimated by comparing the amount of water that could be diverted at Kendall and delivered to the Farmers Ditch through one of the ADS projects with the amount of water actually diverted. Initially, water supply and streamflow conditions were analyzed to estimate the frequency or type of water year when the ADS could be utilized. The available river flow at Kendall was estimated by deducting the diversions by the Amazon and South Side ditches. Transit losses that would occur within the ditch systems were estimated using the information presented in Section 3.3.

5.1.1 Preliminary Facility Sizing

Improvements to the South Side Ditch return channel were implemented several years ago. This channel has 200 cfs capacity. A delivery system that extends this return channel all the way to the Farmers Ditch would eliminate the intervening river losses between the South Side Return and the Farmers Headgate. A potential alignment for this Southside ADS is identified on **Figure 8a**. The system would have a capacity of 200 cfs and the conveyance would be via open channel directly from the South Side Ditch to the Farmer's Ditch at a location just downstream of the Farmer's headgate. This alternative would involve constructing a ditch with total length of 4,400 feet and bottom width of 20 feet. Implementing this alternative would conserve the water lost in transit between the South Side Return and the Farmers headgate, a river length of approximately one mile. A primary consideration with this alternative is crossing the Arkansas River. The lowest cost alternative would involve constructing a discharge structure into the river and a diversion structure on the opposite side of the river with a channel between the two structures. However, the channel would need to be maintained and would likely fill with sediment during high-flow periods. There was a proposed Reclamation project to construct an inverted siphon at this location; however, that project was not implemented because of its high cost. An estimate of cost for the siphon was prepared for the SOR and is noted in **Table 6a**.

5.1.2 Water Savings Analysis

A calculation of the change in water supply to the Farmers Ditch was made, assuming that the deliveries from the Southside return channel would be delivered directly to the Farmers Ditch without further river losses. The difference in water delivered to the Farmers Ditch with this alternative would be 5,600 to 6,400 ac-ft/yr, or 92% to106% of the total amount delivered. This analysis is described in more detail in Section 5.2.2.

5.1.3 Cost Estimates

Project Costs

Project costs for the South side ADS are provided in **Table 6a**. The total cost is estimated to be $2.2 million. $1.9 million of this total would be for a siphon crossing of the Arkansas River.

5.1.4 Additional Investigation

Additional Information Required

Additional information needed to further evaluate these alternatives includes:

- Facility requirements and cost estimates for required upgrades of the South Side Ditch;
- Geotechnical explorations and testing;
- Alignment surveys to confirm project configurations and conveyance system sizing; and
- Selection of a preferred alternative.

A necessary element of an ADS project with the South Side Ditch would be an operating agreement between the Finney County Water Users and the South Side Ditch Company. The agreement should address the conditions to determine when capacity will be available for delivery, the capacity to be available, cost-share arrangements for maintenance, notice issues and delivery responsibilities through the South Side Ditch. Any conditions imposed by the Kansas Division of Water Resources should also be acknowledged.

Potential Alternatives

The potential alternatives have been defined, as discussed above unless GMD3 or local water users identify other options during review of this report. It may possible to eliminate the siphon component and use a short reach of the river for conveyance. However, this option would require frequent maintenance.

This alternative could be made more efficient with improvements to the South Side Ditch identified in Feasibility Study #1.

5.2 Northern Alternate Delivery Project

The Northside ADS project would deliver water to the Farmers Ditch through the Amazon/Great Eastern system. Because of elevation differences between the northside and southside systems, the conveyance will most likely be a pipeline extending from the Great Eastern canal to the Farmers Ditch. Diversions would need to be integrated within the operations of the Great Eastern system. All of the lands receiving surface water also have access to groundwater from wells. Lake McKinney provides storage of surface water and releases can be delivered throughout the service area. The capacity of the canal is 200 to 300 cfs near the upper end of the canal. Information from previous studies indicates that the capacity within the Great Eastern is 150 cfs to 200 cfs at the upper end of the southern branch of the canal. Capacity is reduced to 100 cfs at the lower end. It is anticipated that the capacity in at least parts of the canal would need to be enhanced for the Northern ADS. Identification of sections of the Great Eastern that may need to be enlarged was beyond the scope of this study.

The Northside ADS has not been investigated to the same level of detail as the Southern ADS, evaluated in the South Side Ditch feasibility study described above. An investigation of the Great Eastern system similar to that performed by BMEC for the South Side system would be needed to identify capacity and operational constraints to providing the water from the Great Eastern to the Farmers Ditch. Such an investigation would determine the capacity of the Great

Eastern Ditch from the outlet of Lake McKinney to the point of connection to the Farmers Ditch. This study would also need to document potential capacity enhancement constraints such as crossings, control structures and municipal development.

Operational records for the various laterals and deliveries would need to be reviewed in order to assess the viability of integrating the Farmers deliveries with deliveries to the Great Eastern water users. Some adjustment to Great Eastern operations is anticipated to be needed in order to accommodate deliveries at a reasonably dependable level. We believe that adjustments could be worked out, given that the operations currently in place on the river provide for a rotation agreement among the ditches.

For purposes of this evaluation, we assumed that the conveyance loss in the Great Eastern system is in the range of 35% to 47%. The benefits of this ADS would be the reduction in losses that occur in the river from the Amazon Canal to the Farmers headgate.

5.2.1 Preliminary Facility Sizing and Costs

Project 1: Northside Alternate Delivery

The Great Eastern Ditch could be used to deliver water to a location just upstream of Deerfield with an approximately 13,000-foot-long conveyance system from there to the Farmers Ditch (Alternative 1A). The estimate for this project has been based on a 7-foot-diamter reinforced concrete pipe. A potential alignment and approximate profile for Alternative 1A are provided on **Figure 8b**. The interconnection capacity would be 200 cfs.

Another concept is to convey flows in the Great Eastern to a location where it approaches very close to the Farmers Ditch, at which location an interconnection approximately 2,650 feet long would be made between the two ditches. Alternative 1B is shown on **Figure 8c**. While the 1B interconnection is much shorter, significantly more length of the Great Eastern Ditch would need to be upgraded to carry additional water. A 4-foot-diameter PVC (or HDPE) pipeline would be the preferred configuration for Alternative 1B.

5.2.2 Water Savings Analysis – Southern and Northern ADS

An analysis was conducted to estimate the increased yield that could be achieved with implementation of the ADS alternatives considered for the SOR. The purpose of each is to increase the amount of water available for diversion to the Farmers Ditch. The general operation would be to divert the Farmers water supply at the alternate diversion at times when streamflow conditions would result in substantial loss in the existing river channel.

A study period of 2000 – 2011 was used to define channel loss conditions in the river reach between Kendall and Garden City. This corresponds to a period of low stream flows and incorporates a time when streamflow records are available for both the Kendall and Deerfield gages.

Records of Farmers Ditch diversions and the Garden City stream gage were analyzed to determine times when diversions appeared to be limited by available water supply. Then years were identified when it appeared that alternative deliveries would likely be implemented to enhance deliveries. The available flow at Kendall, quantified as historical flow less the diversions at the South Side and Amazon Canal headgates, was considered available for diversion at either of the two systems. The amount potentially divertible was limited to the ditch capacity.

The analysis was conducted with a monthly time step. The amount of water that could be delivered to the Farmers after deducting transit loss within each system was estimated and compared to the actual diversions made at the Farmers Ditch.

<u>Assumptions for analysis of ADS benefits</u>

1. The diversions for the Farmers Ditch could be delivered through the Great Eastern or South Side Ditch, within the capacity of the ditches and to accommodate the joint operation of the ditches. It is likely that rotation would be necessary to use the South Side Ditch. Operation in the Great Eastern could likely occur with concurrent operation.

2. The conveyance efficiencies for the two systems reflect current conditions. Losses are expressed as a percentage of the amount diverted for delivery. The ranges assumed were 35% to 47% for the Great Eastern and 23% to 32 % for the South Side Ditch.

Summary of Results

The increase in yields to the Farmers Ditch from the South Side Ditch ADS was estimated to be **5,600 to 6,400 ac-ft/yr**, for years when the ADS would be expected to operate. This would occur approximately one-half of the years for the 1982 – 2011 study period. During these years, the Farmers water supply would be increased by 92% to 106% above the 6,000 ac-ft/yr that was historically provided. The average increase in diversions over the entire study period would be approximately 50% of this estimate, or about 3,000 ac-ft/yr, considering inclusion of years when the ADS would not be used.

The increase in yields to the Farmers Ditch from the Great Eastern Ditch ADS was estimated to be **3,800 to 5,200 ac-ft/yr** for years when the ADS would be expected to operate. For this period, the diversion supply would be increased by 64% to 87% above the 6,000 ac-ft/yr that was provided. The increased supply would occur approximately one-half of the years for the 1982 – 2011 study period. The average increase in water supply to the Farmers system would be approximately 50% of the estimate, or 2,500 ac-ft/yr over the entire study period. **Table 4** provides a summary of the increase in supply computed for the two ADS projects.

5.2.3 Cost Estimates

Cost estimates for the two alternatives are $778,000 for the short, pipeline (length = 2,650 feet) and $6,431,000 for the longer pipeline (length = 13,000 feet).

Conceptual-level cost estimates for the alternate deliveries to the Farmer's Ditch are provided in **Tables 6a, 6b, and 6c** and are summarized below:

Alternative	Length of Existing Canal to be Upgraded	Construction Cost (Excluding Canal Upgrades)
1A	~5 miles; Great Eastern Ditch	$6,431,000
1B	~11 miles; Great Eastern Ditch	$778,000
5	17 miles; South Side Ditch Note: Inverted siphon would add $1.9 million to this figure	$284,000

5.2.4 Additional Investigation

Additional Information Required

Additional information needed to further evaluate these alternatives includes:

- Facility requirements and cost estimates for required upgrades of the Great Eastern Ditch;
- Geotechnical explorations and testing;
- Alignment surveys to confirm project configurations and conveyance system sizing; and
- Selection of a preferred alternative.

To implement an alternate delivery system for the Farmers Ditch through the Great Eastern will require an operating agreement between the affected entities, and may include the Kansas Division of Water Resources. The agreement should address at least the following issues:

- Delivery rates
- Frequency and schedule of delivery
- Cost-sharing for maintenance of ditch facilities
- Expected losses in delivery
- Responsibility for necessary control structures or other improvements
- Responsibility and requirements for water measurement and records
- Notice provisions

5.3 River Flow Restoration Project

One alternative considered for improving the efficiency of delivery to the Farmers Ditch is to develop channel improvements in the Arkansas River. This alternative was identified by the committee at a conceptual level to consider what possibilities might exist for such improvement to create a more efficient flow regime at low flows. After consideration of the goals and potential improvements possible, environmental issues and the costs, it was concluded that a low-flow conveyance channel, extending from a diversion point 2.5 miles upstream of the Farmers Ditch to the Farmers may be a feasible alternative to reduce river transit losses. This project does not involve use of either the South Side or Great Eastern Ditches to convey water to the Farmers Ditch. The reductions in transit loss would be achieved by conveying low river flows through a lined channel that generally parallels the existing river channel. The channel would have a capacity of 200 cfs and be supplied from a new headgate.

5.3.1 Preliminary Facility Sizing and Costs

Project 2: Restoration of River Flows

Project Description

The alternative selected for evaluation of this efficiency improvement is an Arkansas River flow-bypass channel extending 2.5 miles upstream of the Farmers headgate. This is a reach of the river known to experience high loss rates. A general plan is shown on **Figure 8d**. This flow-bypass channel would have an assumed capacity of 200 cfs. Conveying flows in this channel would reduce transit losses in conveying water to the Farmer's headgate.

Based on an estimated slope of 7.5 feet per mile, a concrete-lined channel with a bottom width of 12 feet, side slopes of 3(H) to 1(V), and flow depth of 2.5 feet would deliver the required flow. Flow velocity would be approximately 5 fps, assuring sediment movement. The channel would be roughly 4 to 5 feet deep from the ground level and would be located within the river floodplain; therefore, sediment may accumulate in the channel during river flooding episodes. Periodic sediment removal from the bypass channel would be required. Water would be diverted into the bypass channel from the river through a gated intake. For planning it has been assumed that a diversion dam across the main Arkansas River channel would not be required and that the intake could be set such that 200 cfs could be diverted over a range of river flow and stage conditions.

5.3.2 Water Savings Analysis

The channel improvement project would result in more efficient delivery down the river from Kendall to the Farmers headgate. Increased supply was estimated for this alternative by assuming that losses in the reach were avoided at the average rate of loss measured in the Deerfield to Garden City reach for years of low flow (2000 – 2011). This rate is approximately 3 to 4.5 cfs/mi. The reduction in loss due to the installation of 2.5 miles of lined canal is estimated to be 7.5 – 11 cfs. This amount was considered to be added to the supply in months when diversions historically occurred. Additional supply was considered to be available for the entire month when diversions historically occurred.

The estimated increase in supply to the Farmers Ditch would average **2,100 to 3,200 ac-ft /yr** for the use of the low flow channel in 19 years out of 28 that the channel could have improved the yield by operation. The results are summarized in **Table 4**.

5.3.3 Cost Estimates

A preliminary opinion of cost for this alternative was developed based on the general alternative description provided above. This estimate is $1.7 million, as shown in **Table 6d**.

5.3.4 Additional Investigation

<u>Additional Information Required</u>

Detailed mapping will be required in order to select an appropriate alignment and size the bypass channel. Geotechnical explorations and testing will also be needed. Information on river sediment loadings over a range of discharges will be needed to evaluate sediment transport in the bypass channel and to assess the likely sediment removal volumes following flood events, in order to estimate O&M costs. Requirements for maintaining instream flows during bypass operations will need to be determined.

Potential Implementation Obstacles

This alternative could involve significant environmental review and permitting hurdles that would need to be overcome because of changes to the instream flow regime. Selection of an alignment and flow diversion arrangement that assures good performance, and is not overly costly to operate and maintain, may also prove to be challenging.

Potential Alternatives

Reduction of seepage losses by some sort of river channel lining project has been suggested, but is not considered to be viable because of expected permitting difficulties as well as maintenance challenges and potentials for damage during larger flood events.

5.4 Bear Creek Valley Recharge Project

The Bear Valley recharge project would provide a channel to divert high flows from the Arkansas River for recharge in a natural depression located south of the South Side Ditch service area. A location and size of the channel has been proposed for this study for the purpose of obtaining an initial cost estimate of the project. More detailed evaluation would result in optimization of both the capacity and location of a channel. This study has estimated flows that may be divertible from the river under several assumptions about constraints on such diversions. A new water right would be required for the project, since these diversions would not be made with existing facilities or water rights, and would be subject to pre-existing water rights.

The project configuration was developed at a preliminary level to assess operation, yield and costs. The parameters necessary to define the project include the following:

- Operational characteristics (flow conditions and frequency of diversion)
- Location of the recharge area
- Location of diversion site
- Configuration of the diversion works, canal, discharge facilities
- Canal capacity

The project would divert high flows from the Arkansas River to a natural depression, located in Sections 30 and 31, T25S R36W, 24, 25, 35 and 36, T25S R37W, 02 and 03, T26S R37W (See **Figure 9a**). The land has been described generally as non-cropped land that could be used for infiltration with minimal disruption of current use, assumed to be primarily grazing. The site is described in Feasibility Study No. 3. Local experience with the infiltration characteristics at the site are based on large precipitation or snowmelt events. The area that could receive high flow deliveries proposed with this project could be up to 1,000 acres, depending on the quantities diverted.

This recharge site was evaluated as one of the alternatives in the 2008 study of Enhanced Aquifer Recharge completed for the KWO (Ref. 5) (*Bear Creek Depression, site S-01*). The source of supply considered in that study was a lateral from the South Side Ditch extending 9,500 feet. The site was identified as containing loamy fine sand soils with high infiltration capacity. The initial infiltration rate at the site was estimated to be 1.5 to 3.0 feet/day. The alternative graded relatively high compared to other recharge sites identified in that study due to the high infiltration capacity, size of the area available for recharge and limited amount of site work needed for the project. A negative consideration relative to other sites was the limited number of nearby wells that would benefit from recharge. The cost to develop the project was estimated to be $87,000 and the recharge capacity was estimated at 225 to 450 ac-ft/day.

The site information and recharge characteristics described here were derived from the previous study (2008, Ref. 5). No further investigation of site conditions or factors that might affect managed aquifer recharge, such as ownership, was made for the SOR and no further site reconnaissance was conducted. The 2008 report noted that there was limited development on the site. That study identified oil and gas wells present in the area and noted that some site work may be needed to isolate such facilities

The current alternative differs from the previously identified alternative due to the source and magnitude of water supply. A diversion canal constructed from the Arkansas River to the site, a distance of approximately 7 miles will be a project of much larger cost, due to diversion and conveyance requirements. Water would not be delivered every year, but only during high flow conditions.

The water supply expected to be available for this project has been estimated at a preliminary level for this study, using a number of assumptions about the nature of the water right that might be obtained, capacity to divert and streamflows that could be diverted. These aspects are described in more detail below. A water right for this project would be constrained by requirements for downstream water rights or environmental purposes. Preliminary assumptions have been made for this study which should be evaluated and validated in more detail in subsequent studies. It may be that flows available for diversion would be determined through a permitting process that would also consider environmental issues and potential constraints. Similarly, allowable diversions may be determined through a water right permitting process that would include limitations to protect downstream water right holders, both surface and groundwater.

Project benefits for aquifer recharge can be either in terms of water level enhancement to increase the amount of water available to be pumped where the water levels have declined to the point where pumping is limited, or to reduce the pumping lift, while extending the life of the aquifer in the general location of the project. This second benefit is considered the more predominant opportunity for this project. A groundwater modeling analysis would be necessary to quantify this benefit in terms of aerial extent or extended life. Such analysis was carried out for the 2008 regional feasibility study of Enhanced Aquifer Recharge for other recharge projects in the vicinity. Similar analysis could serve to quantify benefits for this project. The focus on the quantitative analysis of the project has been on possible amounts that could be diverted from the river, which can then be compared to expected project costs. Savings would result from more efficient recharge of diverted water as compared to recharge in the natural river channel and river outflow.

A canal that would divert from the south bank of the river would extend from just upstream of the South Side Ditch headgate for 7 miles and discharge to the natural depression. The channel would be unlined in native overburden material, constructed by excavation and fill. Additional costs for recharge site development are not included. Such on-site development work could include leveling and berms to pond water and induce recharge. The operating agency will need to have permanent access to the site in order to adequately manage the project and to make post-construction adjustments to maintain rates or recharge.

The project would require that adequate measuring devices be installed to document the amount of water diverted from the river and delivered to the site. Evaporation data will also need to be collected to develop a water budget and accounting for the project.

Given the soil properties on the south side of the river, it is expected that there could be a significant amount of seepage from the recharge conveyance channel. We have not made an estimate of seepage rates that could be expected, but some significant percentage of diversion would be expected to return to the stream corridor as gains to streamflow or accrual to the alluvial aquifer. It has been judged that the cost of lining this canal would not be warranted, given the expected frequency and variability of these diversions. Channel flow monitoring should be made at several control sections to document losses and gains to the river.

5.4.1 Preliminary Facility Sizing and Costs

Project 3: Bear Creek Valley Recharge and Flood Mitigation Project

GMD3 has identified an opportunity to use a portion of the Bear Valley, located as shown on **Figure 9a**, to recharge the Ogallala Aquifer and conjunctively manage surface and groundwater to improve overall water use efficiency. Geologic conditions in the Bear Creek Valley, located south of the river, are favorable with respect to recharge (see **Figure 9b**). During high flow periods on the Arkansas River in the vicinity of the Amazon Ditch and South Side Ditch headgates, flows up to 700 cfs, or potentially up to 1,400 cfs (for a larger capacity operation) would be diverted from the river for recharge of the aquifer. The capacity range was evaluated, in terms of facility requirements and costs, to provide an idea regarding potential economies of scale. This type of "flood skimming" operation would coincidentally reduce flood discharges on the Arkansas River providing benefits to downstream communities and agricultural interests with lands in the floodplain.

Project Description

The potential project would include a diversion from the Arkansas River approximately 1.9 miles upstream of the South Side Ditch headgate. Water diverted from the river would be conveyed by open channel to the recharge area generally following the alignments shown on **Figure 9a**.

This site is located approximately one mile south of the South Side Ditch with the upper portion of the recharge area located where the surface evidence of Bear Creek disappears into a closed basin. This site is located on, or very near, the Bear Creek Fault. Information available from a database on the Kansas Geologic Service website indicates that wells located within 2 miles of the site are generally completed to a depth between 50 and 150 feet. The depth to bedrock is between 50 and 250 feet. Observed water-level changes indicate the water surface has fallen from about 50 feet below the ground surface in the1960s to more than 80 feet below the ground surface today.

The river diversion will likely include a low weir across the river to provide a stable control section for a headgate structure on the south side of the Arkansas River. For planning and cost estimating, we assumed that the weir would not need to be a gated structure; however, gates could be required depending on hydraulic factors to be considered during the feasibility phase of evaluation. The intake to the recharge supply channel would be a gated headgate structure

The headgate and supply channel were sized for 700 cfs. The channel would have a bottom width of 50 feet and flow depth of 4 feet, and slope of 0.00042.

5.4.2 Estimated Water Supply Available

A study of the streamflow records was developed for a 30-yr study period of 1982 – 2011, to estimate amounts of water that might be available for the diversion project described above. This study assumes that a new water right could be obtained from the State of Kansas for diversion of high river flows for aquifer recharge when such flows are not needed to satisfy downstream water rights. The study determined that the opportunity for diversions by a new water right for aquifer recharge would be infrequent and of short-duration. One possible exception may be for winter flows in some years when the ditches are not being used for direct flow irrigation. Some opportunity could exist for winter period diversions after Lake McKinney has been filled. There would be constraints to winter operations and rates of diversion would be lower than the high flow diversions during the irrigation season. Diversion of lower flows would mean a greater percentage of loss due to seepage from the unlined canal. Operation and maintenance of the recharge facility may also be more challenging during the winter season when available flows would be relatively lower. The yield estimates made for this SOR assume operational criteria that would make winter diversions possible under some conditions. At times when reservoir releases are being made from JMR for irrigation, recharge diversions would not be made.

Previous studies have estimated available flow for diversion from the Arkansas River at Garden City using various assumptions about river flow conditions that would be required to protect existing uses and water rights. In a previous study for GMD3, yields for an off-channel reservoir or recharge project were estimated for the study period of 1970 – 1999. (Spronk Water Engineers, Inc. 2001) Average annual yield was estimated to range from 24,000 to 42,000 ac-ft/yr, assuming a diversion capacity of 400 cfs. The study assumed that all flows in excess of existing diversions were available for diversion, subject to bypass flow requirements. Yields were determined to be insensitive to the diversion capacity.

In a study completed for the KWO for enlargement of Lake McKinney, the average annual storable flow was estimated to be approximately 40,000 ac-ft/yr for the period of 1975 – 2006. This estimate was limited by available diversion capacity in the Amazon Canal, but was not constrained by storage capacity. Flows in excess of historical diversions and minimum flow rates were assumed to be available for diversion.

Flows available for diversion for a managed recharge project were estimated for the Feasibility Study No. 3. A flow rate of 100 cfs was estimated to be available 25% of the time over the period of 1980 – 2005. This assumed that historical stream infiltration above Garden City would not be available for diversion.

The flow available for diversion from the river was evaluated for the SOR using the general assumption that diversions could occur at times when river flows exceeded the diversions being made by the ditches at the three diversion locations, with some bypass flow left in the river. Excess flow would be determined by comparing the flow at Kendall to the downstream diversions and checking the flow at the Garden City gage to determine if additional flow was available in the study area.

Diversion Criteria assumed for the SOR:

- Daily streamflow and diversion data were used.
- Flow at Kendall was compared to the sum of the downstream diversions.
- Flow at Garden City was checked to see if available flow existed during irrigation season (> 20 cfs)
- Flow in excess of a bypass amount was considered to be divertable. The amount of the bypass was varied for evaluation. Bypass was set at 500 cfs in the irrigation season and 100 cfs during the winter.
- The flow available for diversion was the minimum of [(Q – existing diversions) or (Garden City Q – 20 cfs)] or [Q – Bypass Q]
- Diversions would not occur when releases of Kansas water are being made from JMR.
- A minimum diversion rate was applied (100 cfs). The diversion would not be operated at flows less than this threshold.
- Diversion was limited to the canal conveyance capacity assumed. (Two capacities were considered for this study; 700 and 1,400 cfs)

Results

The operation study produced daily flow rates of divertible flow for the stated assumptions. The assumed canal capacity is 700 cfs. Results of the divertable flow analysis are summarized by monthly flow totals for the 30-year period of 1982 – 2011 in **Table 5**. **Appendix D** provides backup calculations and results from several sensitivity analyses for several assumed parameters.

Deliveries to the recharge site would be reduced for conveyance efficiency, as discussed in the results summary below.

- Diversions for recharge could be made in 40% of years. (12 out of 30)
- Divertible flow is estimated to be 20,900 ac-ft/yr over the entire 30-year period. This equates to approximately 52,000 ac-ft/yr for years when diversions could be made.
- A conveyance efficiency of 75% to deliver water from the river diversion to the recharge site was assumed to provide estimates of water available at the recharge site. This would translate to 15,700 ac-ft/yr delivered to the site over a long term average.
- The rate of 700 cfs assumed for this study appears reasonable, given the size of the site and infiltration capacity estimate provided in Reference 5.

Whether or not the project is operated during the non-irrigation season would likely affect the yield and the frequency and duration of project operation. Under currently assumed operations, approximately one-half of the average annual yield would occur during the months of November – March. The potential for winter operation would depend on a number of factors, including:

- Bypass flow requirements that might be imposed on the project during the winter. If the winter bypass rate were increased from 100 cfs to 200 cfs, yield would be reduced to about 15,500 ac-ft/yr (11,600 delivered)
- The ability to divert flow at the river diversion structure during winter conditions with relatively lower discharge rates in the river.
- Winter operations of river diversions, canals and recharge basins typically require more oversight due to ice and snow.

The capacity of the conveyance canal would not affect the expected frequency of operation. However, the total volume of diversion would be limited by canal capacity. If the capacity were reduced from 700 cfs to 500 cfs, average annual diversions would be reduced by approximately 85%, to 17,800 ac-ft/yr.

The amount of water that could be recharged at the site is approximately estimated based on topographic conditions at the recharge site and estimated infiltration rate. The volume of the recharge site is estimated to be approximately 10,400 ac-ft. Assuming a delivery rate of 1,000 ac-ft/day at the recharge site, an initial infiltration rate of 1.5 feet/day would accommodate this supply.

5.4.3 Cost Estimates

Project costs are estimated at $ 8.0 million. **Table 6e** is an itemization of the probable costs.

5.4.4 Additional Investigation

The results of this study can be used to assess the potential limitations on a water right permit for this diversion and recharge project. Downstream water rights mitigation has been incorporated into this analysis by deducting downstream diversions from available supply and considering a bypass flow. However, the downstream needs that would affect the magnitude of the bypass have not been evaluated for this study. Such considerations would involve downstream groundwater rights, environmental considerations and aquatic and riparian habitat considerations. Discussions with the State officials are recommended to identify criteria that might be applied to such an application.

A more detailed analysis of the impacts of this project on aquifer levels and projected long term pumping benefits should be evaluated. Groundwater modeling studies would be warranted, given the significant investment that would be required for the diversion facilities.

Information about permitting conditions that might be applicable should be obtained from the appropriate agencies. Typically, mitigation requirements would be identified and addressed during a permitting process. The specific cost of permitting activities should be considered. Current estimates include project permitting as part of the contingency cost of the project.

The recommendations contained in the 2008 Feasibility Study No. 3 (Ref. 5) for further investigation of recharge projects should be undertaken. These include:

- Initial soil and subsurface characterization;
- Detailed soil analysis, groundwater investigation and percolation tests;
- Large-scale parameter or pilot testing.

Project benefits should be evaluated on the basis of yield amounts and frequency of operation during high-flow periods. Operation during normal winter seasons would be somewhat uncertain until more detailed analyses are completed. Also, winter operations can potentially be enhanced when project operating experience is gained after implementation.

5.5 Sprinkler Pits in South Side Ditch Service Area

The South Side Ditch has a service area of approximately 10,000 acres and the area using surface water was most recently documented to be 6,300 acres in the mid-1990s. Effectively all of the service area is irrigated by center pivot sprinkler and the shareholders do not routinely use surface water deliveries for sprinkler irrigation. There are presently approximately 68 full or partial pivots in the service area (2011 aerial photography) (See **Figure 10**). The viability of constructing regulating ponds (sprinkler pits) which would facilitate using surface water delivered from the ditch system to operate the center pivot sprinklers, has been demonstrated in the Great Eastern Ditch service area. Application of this type of operation in the South Side service area may also be attractive.

The sprinkler pits would not provide a significant amount of storage relative to the application rates. They basically are an extension of the ditch system. The purposes of the ponds are to 1) settle out sand, silt or other sediment, 2) provide short-term storage to regulate peaks or interruptions to the supply and 3) provide a pumping sump for submergence of the pump intake (Allen, Keller and Martin, 2000). It is expected that each sprinkler installation would continue to also use groundwater and that the ponds would provide the flexibility to use either ditch supplies or groundwater. The primary benefit of this operation is to reduce pumping costs at times when surface water is available. One criteria to evaluate the benefit of the ponds is to compare the cost to construct and use with the reduced pumping cost.

Several considerations make the benefits of adopting of this management approach on the South Side service area less certain than in the Great Eastern service area.

1.) The soil types in the South Side service area are relatively more permeable than in the Great Eastern service area. Unlined ponds are used north of the river. If lining of ponds on the south side is required, costs will increase.

2.) The ponds in the Great Eastern are being constructed by the Garden City Company, with their own equipment and labor. The GCC owns most of the land served by the Great Eastern, which is leased to tenants. The construction of ponds in the South Side service area may need to be constructed by local contractors, possibly resulting in higher costs. The ponds under the Great Eastern have been constructed and refined based on actual operating experience, some of which have very site specific characteristics with respect to sizing, layout and number of sprinklers served from one pump and pond. Similar experience will need to be gained in the South Side service area.

The characteristics of "typical" Great Eastern sprinkler pits were used to generate a typical size, pump capacity, and layout. The single largest cost for a sprinkler pit appears to be the cost of delivery pipe, which is typically 10-inch diameter PVC. Delivery of water from the main ditch or laterals directly into the ponds by gravity would reduce overall pipe lengths and associated costs. We have assumed for this evaluation that the South Side sprinkler pits could be situated adjacent to the main ditch or laterals, which would avoid the need for pipelines to supply the sprinkler pits.

The sprinkler pits could potentially be located and used to serve multiple sprinklers. The issues that would affect this approach are the proximity of sprinklers to each other and the number of sprinklers an individual irrigator is operating. Multiple operators using one pond could cause irrigation scheduling issues that would need to be resolved.

5.5.1 Preliminary Facility Sizing and Costs

Project 8: South Side Ditch Sprinkler Supply Pits

Project Description

During the November 2013 site visits, a GEI engineer was shown several sprinkler pit installations in the Great Eastern service area and was able to make some measurements of the pit dimensions and to discuss the configuration of these installations with a GMD3 representative. Based on the site visit and discussions, and other guidance from GMD3, GEI developed the following description of a "typical" sprinkler supply pit installation. The sprinkler pit concept is depicted on **Figure 8e** and includes:

- A water supply basin or pit, constructed of cut and fill, with interior dimensions of roughly 115 feet by 270 feet and depth of 4 to 6 feet. The pit could be lined with a geosynthetic material (or potentially clay, if available) to reduce seepage losses should seepage become an issue; however, costs for lining were not included in the estimate developed for this efficiency improvement.

- The pit would be supplied by gravity through pipeline extending from a turnout on nearby main ditch or lateral to an inlet structure at the pit. The pipeline would be at least 10 inches in diameter and capable of delivering the capacity of three 600 gpm center pivots, about 4 cfs.

- An intake structure, leading to a pipeline and pumping installation, would be located at the opposite end of the pit from the inlet. The pipeline leaving the pit would be at least 10 inches in diameter and would operate at 50 psi. The operating pressure and hydraulic design will need to be confirmed during design. The 10-inch pipe would branch to 4 smaller pipes (6 inches in diameter) delivering water to the four center pivots. The lengths of the pipelines will vary, depending on the sprinkler pit location.

- A pumping unit, located near the pit, would be a natural-gas driven installation capable of delivering water to three of the four center pivots simultaneously (1,800 gpm or 4 cfs). The pumping capacity will need to be confirmed during later design studies. Cost estimates were based on a 70 HP pump.

Project Benefits

Implementation of additional sprinkler pits, and associated water delivery facilities, at key locations in the South Side Ditch service area would allow improved usage of surface water supplies for irrigation, when these supplies are available. This would reduce drawdown of groundwater levels and reduce overall energy consumption for irrigation.

5.5.2 Water Savings Analysis

In a normal year, approximately 12 inches of surface water could be supplied to sprinklers from surface water supply. If the cost to pump this supply is reduced by $ 17/ac-ft, then the annualized savings would be $2,125 for a 125 acre pivot, or **$8,500** per pit serving four sprinklers. The savings in pumping cost has been initially estimated by assuming a pumping lift of 100 feet and cost of natural gas of $4.61/mcf. A number of other factors related to efficiency are implicit in these calculations. Actual records or information about the cost of pumping using natural gas as fuel was not obtained for this study. The price of $4.61 was a 1998 value documented previously for this region. (Ref. 9) This could be compared to the annualized cost for development of a typical pit at a cost of $516,100 (see Section 5.5.3), which results in an annual cost of **$50,000** /yr (assuming 15-year life, 5% interest rate). Based on these estimates of potential benefits and costs, sprinkler pit development in the South Side service area may not be practical. Further, due to the variability of water supply from the Arkansas River, this reduction in pumping may not be expected every year. An unquantified potential benefit of providing sprinkler pits would be extending the life of the aquifer supply in the immediate vicinity of the South Side Ditch.

5.5.3 Cost Estimates

<u>Project Costs</u>

Estimated cost for a typical sprinkler pit and associated water delivery facilities is shown in **Table 6f**. The estimate assumes that one mile of 10-inch-diameter pipe is required to distribute water to the center pivots. The actual lengths will vary depending on the pit location relative to the surface irrigation system. Other assumptions are noted in the project description provided above. Estimated cost for a typical sprinkler pit system is $516,000, as shown in **Table 6f**.

5.5.4 Additional Investigation

<u>Additional Information Required</u>

Additional information needed to further evaluate this alternative includes:

- Selection of the best locations for the sprinkler pits in the South Side Ditch service area, based on the location of surface irrigation facilities, groundwater pumping levels, and inputs from GMD3 and irrigators;
- Site surveys and topographic mapping; and
- Geotechnical and soils information, as required to design the facilities.

Potential Implementation Obstacles

No particular obstacles to implementation of sprinkler pits have been identified; however, we assume that cooperation among irrigators will be required.

Potential Alternatives

Alternatives that would provide similar benefits have not been identified.

Sprinkler Pit Configuration Considerations

One issue raised in development of this alternative was whether the sprinkler pits can be configured to efficiently serve more than a single sprinkler installation. The following are the considerations relative to having a sprinkler pit serve multiple center pivots:

Pros

- The primary benefit would be to reduce the unit cost of installing ponds per sprinkler. Since the primary purpose of sprinkler pits is operational rather than to provide on-site storage, the pond size should not need to be increased proportionally to the acreage being irrigated from it.

- Continued reliance on groundwater in the service area will help to facilitate having multiple sprinklers served by a single sprinkler pit.

Cons

- Locating a sprinkler pit to serve multiple sprinklers may not be feasible throughout the service area. Further study will be required to determine the locations for the sprinkler pits.

- Multiple irrigators operating from a single sprinkler pit will require coordinated operation. For these installations, the pump costs may be higher because simultaneous operation would be required.

5.6 Amazon Ditch Flume Rehabilitation

The information about the purpose and need for this project alternative has been obtained primarily from the phase II report on the Amazon Flume Evaluation, by Wright Water Engineers, December, 2012. In summary, the flume is a wood timber structure, constructed in 1954 to cross Sand Creek, located about 11 miles from the diversion works on the Amazon Canal. The capacity of the flume is 600 cfs. Several alternatives were considered in the Phase II study. The alternative implemented was to totally replace the flume at the same capacity. The estimated cost was $1.2 million.

The improvement to water efficiency was to eliminate the leakage that occurred with the flume.

> *"The timber flume structure has shown extensive leakage due to deterioration of synthetic liner, age-related effects from prolonged exposure to water and abrasive materials, such as sand and other atmospheric conditions."* (2012, Ref. 8, pg. 5)

The quantity of leakage from the flume was not estimated or reported. No estimate of leakage has been made for this study. An overarching purpose for replacing the flume was to re-establish structural integrity of the structure, which is an improvement to the dependability of the canal.

5.7 Lining Ditch and Laterals Near Municipal Supply Wellfields

This project alternative was initially identified as a response to concerns about water quality degradation in several public water supply well fields located in the study area. The purpose and proposed project alternative was described as follows:

Lining of Ditches near Public Water Supplies. *The water in the river channel is very poor quality and infiltration beneath the ditch channels near municipal well fields is believed to have caused contamination of the water supplies of the cities of Lakin and Deerfield. The project will provide and evaluation of the cost and effectiveness of lining stretches of the ditches that pass near well fields in reducing the degradation of drinking water quality. An analysis of the effect lining those portions of canal would have on the overall drinking water supply for those communities with and without water treatment facilities will also be performed.* (Fourth semi-annual progress report, Oct. 2013)

After initial review of the available data, modeling information and benefits that could be accrued from this project, it was concluded that it was premature to configure and cost out a specific canal lining project. There are a number of factors that should be investigated before a specific project can be defined that would address the issue of water quality in the well fields. These would include:

- Water quality for the Great Eastern and South Side ditches.
- Water quality in the aquifer at the respective well fields.
- Seepage rates from specific reaches of the canals and laterals that could affect aquifer water quality.
- Groundwater modeling of in the vicinity of the well fields to evaluate seepage flows and potential water quality impacts to public water supplies.

Based on data review for this study, it was concluded that there was insufficient data for water quality, localized ditch seepage rates and water quality impairment in the public water supplies to identify specific project requirements. Additional data collection should be undertaken to address these issues. It should be noted that lining reaches of ditches to reduce seepage could affect the water levels in adjacent well fields.

6.0 Low-Head Hydro Potential Locations

Project 4: Small Hydroelectric Facilities

There are a number of potential hydroelectric power generation opportunities that could be developed on the existing system of ditches within the GMD3 boundary. These include: developing the elevation drop on the Frontier Ditch return flow to the Arkansas River, an elevation drop of 11 feet; a hydro installation on the 4-foot drop structure located on the South Side Ditch; and (if it is implemented) developing hydro as part of efficiency improvement with either Alternative 1A or 1B (20-foot drop from the Great Eastern Ditch to the Farmer's Ditch) described previously. Alternative 1B would probably be the most advantageous opportunity for hydropower development.

Hydrokinetic-type hydro-turbine installations also could be considered at various "hard" structures along the ditches, such as bridges, culverts, and control structures. Hydrokinetic units rely on channel flow velocity rather than head drop. Any type of hydro development (whether conventional or hydro-kinetic) will require a relatively dependable water supply to generate sufficient energy to offset the costs of purchasing generating equipment and providing the required civil structures associated with hydro development.

For preliminary consideration, we developed a concept for hydro development on the Frontier Ditch return flow channel, as described below. Findings from this concept are discussed relative to other potential hydro development options.

Project Description

Figure 8f shows the location of a potential hydroelectric power development on the Frontier Ditch, which is located at the location where water not diverted for irrigation off the ditch is returned to the Arkansas River. There is an elevation drop of 11 feet over a distance of about 75 feet, based on approximate field measurements made by a GEI engineer in November 2013. Flows in the return channel to the river were estimated on a daily basis for the period 1980 to 2011 by SWE and converted into monthly flow-duration curves that were used to estimate power output and energy production.

A 5 kilowatt (kW) turbine-generator unit appears to be an appropriate size installation (hydraulic capacity of 7 cfs at a net head of 10 feet). Assuming typical efficiency and hydraulic operating ranges a unit like this would generate an average of 8,890 kilowatt-hours (kWh) per year with generation occurring mainly in the months of April through October. This corresponds to a hydroelectric unit capacity factor of 35% during the operating months and only 20 % over the entire year. The capacity factors are considered to be very low.

In addition to the turbine and generator, an intake structure, penstock, and small tailrace would be needed. The penstock would be 24 inches in diameter and about 75 feet long. The hydro unit would be located approximately 0.3 mile from an existing electric distribution line along U.S. Highway 50. We assumed that a tie-in to this line would be possible.

Project Benefits

Generation of 8,890 kWh per year could offset energy currently assumed to be produced from fossil-fuel sources. The hydro unit capacity factor is very low and this may make negotiations with a power purchaser more challenging. Assuming that energy may be valued at $0.08 per kWh; average annual revenue would be $711. This small annual benefit is not likely to cover the cost to develop the hydro installation, which is described below.

Project Costs

As shown in **Table 6g**, the estimated cost is $29,500, equivalent to $5,900 per kW of capacity, with annual cost of approximately $2,900 per year. In our experience, this per kW cost is typical of micro-hydropower installations.

Additional Information Required

Additional information needed to further evaluate this alternative includes:

- Site survey and topographic mapping;
- Geotechnical explorations and testing;
- Information on electrical system connection potentials and requirements;

- Contacts with the local REA and estimates of the value of energy produced; and
- Contacts with equipment suppliers to obtain budgetary price estimates

Potential Implementation Obstacles

The primary obstacles to implementation are most likely to be cost relative to potential benefit and securing interconnection approval from the local REA. There will be a requirement to secure a regulatory approval from the Federal Energy Regulatory Commission.

Potential Alternatives

Potential alternatives are identified above. Developing hydropower on the drop from the Great Eastern Canal to the Farmer's Ditch under Alternatives 1A or 1B described above may be more attractive than the Frontier Ditch depending on the amount of water that can be delivered. If a 100 cfs capacity turbine unit, operating at 20 feet of head (140 kW) can operate with the same capacity factor as indicated for the Frontier Ditch, average annual generation would be 245,000 kWh. The cost for this installation may be less than $5,900 per kW, because the operating head is greater. However, even if the cost is reduced to $4,000 per kW, the development is not likely to be attractive unless the unit capacity factor is higher than 20% on an average annual basis.

7.0 Conclusions

The projects described in this report have been configured at a conceptual level for the purpose of location, sizing and preparing preliminary cost estimates. Further investigation is necessary for each project considered beneficial to optimize size for the quantities of water involved, upon more detailed site investigation.

This report provides the descriptions of the purpose of each project, the basis in data and analyses to quantify benefits, or savings in water for each project for which this was possible with available information and data, and a layout and cost estimate for each. As described in the report, the project configurations were prepared based on the list and description of needs or inefficiencies to be addressed, as developed initially by the water users, observations of site conditions, and with the judgment of the consultants applied as to what would be technically feasible for each.

7.1 Comparison of Project Benefits and Costs

A comparison of project costs to the amount of water savings or yield can be made for several of the alternatives included in this study. This is appropriate for the ADS projects which would increase diversions by the Farmers Ditch. Other comparisons can be made for the South Side sprinkler pits related to pumping costs and the Bear Creek Valley recharge project with respect to diversions for recharge.

Costs for the ADS projects range from $340 to $390/ac-ft for the South Side ADS with a siphon crossing the Arkansas River ($44 to $50/ ac-ft without the siphon), to $150 to $200/ ac-ft for the Great Eastern ADS. These unit costs are based on average annual increased diversion during operational years. The river channel improvement alternative is higher, estimated to range from $538 - $819/ ac-ft. This alternative is more expensive than the canal ADS projects due to:

- Lower yield, due to the limited length of canal installed along the river;
- High cost of lining a channel along the river right of way;
- Existence of the South Side return channel already in place;
- Ability to divert flows at Kendall, upstream of residual channel loss that would still occur with the river restoration.

The cost for the Bear Creek Valley recharge project is estimated at $200/ ac-ft/yr for years of expected diversion. The cost expressed for the estimated average annual yield over the entire study period, including years of no diversion, (15,000 ac-ft/yr), would be $500/ ac-ft/yr.

Costs for the South Side sprinkler pits can be compared to estimates of reduced pumping costs in the service area. The estimated savings of pumping cost was $17/ac-ft, resulting in an overall reduction of approximately $8,500/yr. for four sprinklers.

The magnitude of the benefits that could be obtained from each project could be refined with more detailed data or analysis. The magnitude of benefit for each project will depend to a certain extent on operating criteria, ultimately to be determined by the water users. Several examples are summarized below:

- The ADS projects have a range of possible operational plans, depending on the nature of agreements with the two ditches, the extent to which ditch capacities would be enlarged and frequency of operation. Water users should review and develop a more defined plan that considers the issues identified in this report.

- The channel improvement alternative to construct 2.5 miles of new lined channel was considered the most viable option for flow restoration in the river, given the costs of seepage reduction measures implemented within the bed of the Arkansas River. Other alternatives are considered to be significantly more expensive. This study provides the criteria and parameters to evaluate costs and potential savings in water for a longer reach of lined channel at a feasibility level, if additional costs would be considered feasible.

- The costs of the South Side sprinkler pits should be refined with more direct user input regarding feasible pond siting, feasibility of operation with shared ponds, and interaction with the GCC concerning costs, operations and experience gained. This report has stated the parameters to be considered and estimated benefits in reduced pumping cost that are possible, based on information available for this study.

- For the Bear Creek Valley recharge project, uncertainties include: the extent of the area to be inundated during recharge operations; whether or not wintertime operations are warranted at flow volumes indicated in this study; and ultimately what capacity of canal may be considered feasible, given the frequency and magnitude of water available. This study provides a tool to assess these issues at a reconnaissance level of detail. In addition, there are threshold issues related to the quantity and limitations that could be associated with a water right for the project that would affect expected yield.

Benefits for a potential recharge project would depend on how the extension of the aquifer life is valued. This project provides a basis to estimate quantities to be recharged and project construction costs. Water levels would be raised as a result and corresponding reductions in streamflow would result. The benefit of the increased water levels could depend in part whether the project is operated as a water bank, with increased water supply for participants, or acts to extend the life of the aquifer. No critical areas in the vicinity of the project were identified where pumping has been stopped due to water level decline. Extension of the life of the aquifer could be estimated with groundwater modeling and an economic analysis of the value for assuring future groundwater irrigation supply.

For the most part, the environmental impacts resulting from implementation of alternatives described in this report are expected to be minimal, due to the limited changes in streamflows that are anticipated. There would be localized impacts associated with construction of alternatives involving new structures on the Arkansas River. Compliance with federal, state and local permitting requirements will be required, including a Corps of Engineers 404 permit and endangered species consultation. The two canal ADS alternatives to remove water from a 20-mile reach of the river during periods of low flow and no flow at the downstream end of the study reach would not modify flow conditions significantly. An exception would be the Bear Creek Valley recharge project, which would divert high flows from the river. The nature of the impacts to species and habitat from this operation would be expected to be evaluated in the permitting process. This study has addressed this issue by assuming a seasonal bypass flow rate. It is beyond the scope of this study to quantify instream flow requirements. However, as described previously, assumptions were made concerning the amount of flow that might be required to be maintained in river reaches affected by the alternatives.

7.2 Prioritizing Future Work

The project descriptions include discussion of additional investigations that would be needed prior to implementation of the alternatives. To prioritize the next steps for further studies leading to implementation, it will be necessary to compare the relative costs and benefits for the alternatives. Several of the projects are mutually exclusive, and priority would be assigned to a best alternative. For each of the projects, operational feasibility must be reviewed by the affected water users. Issues that will affect operations of each project have been identified in the report. The following list is provided to prioritize next level of investigation:

- Compare the project benefits and costs to weigh the relative benefits. Since not all of the projects are evaluated on a common basis, this comparison should be done in consideration of the specific objective (i.e. recharge vs. increased surface diversions for irrigation).

- Obtain input from the water users to identify most beneficial project (s) given the costs, amount of water savings involved, with consideration given to operational feasibility.

- Follow-up with further investigations described in the report for project (s) assigned high priority.

8.0 References

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Tables

GMD3 System Optimization Study

Table 1
Annual Streamflow, AF

Water Year	Frontier Ditch Diversion	Coolidge Gage	Stateline Flow	Syracuse Gage	Kendall Gage	Deerfield Gage	Garden City Gage	Dodge City Gage
1982	10,091	71,649	81,739	67,457	61,272	-	79	25
1983	8,551	158,396	166,947	146,739	138,505	-	391	38
1984	6,609	190,688	197,296	180,623	169,596	-	7,063	2
1985	8,729	236,632	245,361	231,726	216,460	-	39,988	1
1986	7,110	224,992	232,102	233,658	218,232	-	22,035	3,645
1987	9,761	515,220	524,981	494,838	457,800	-	315,769	248,035
1988	9,868	228,057	237,925	230,923	215,734	-	59,737	27,385
1989	10,209	135,009	145,218	133,402	126,271	-	33,498	109
1990	9,864	80,734	90,598	78,059	75,507	-	10,878	-
1991	8,025	75,684	83,709	65,666	64,140	-	1,560	-
1992	6,358	78,600	84,958	74,332	72,099	-	-	-
1993	5,080	115,083	120,162	105,631	100,798	-	12,655	25
1994	8,215	119,899	128,114	116,013	110,321	-	17,854	-
1995	9,848	286,312	296,160	271,593	253,028	-	136,773	31,605
1996	8,653	265,973	274,626	268,546	250,244	-	148,151	29,954
1997	6,595	275,369	281,964	259,608	242,035	-	141,226	64,080
1998	8,363	415,702	424,065	412,374	382,160	-	277,099	198,803
1999	9,255	527,343	536,598	518,953	479,920	466,101	391,420	311,471
2000	10,985	276,375	287,360	262,375	256,561	158,902	121,022	73,510
2001	8,407	180,776	189,184	168,949	171,565	112,766	80,750	11,314
2002	9,235	66,600	75,835	61,565	62,901	26,561	15,334	-
2003	5,958	29,948	35,906	25,076	25,623	2,601	0	950
2004	8,201	60,064	68,266	52,896	45,230	3,010	-	-
2005	6,616	89,187	95,803	82,511	78,047	14,797	-	-
2006	7,327	57,431	64,759	49,596	44,826	2,872	-	-
2007	8,296	125,419	133,715	120,391	120,109	43,342	54	-
2008	8,299	98,786	107,086	84,785	83,162	20,178	65	-
2009	8,138	101,236	109,374	92,276	91,818	27,029	71	-
2010	7,867	109,408	117,275	103,866	101,180	37,562	975	-
2011	7,345	63,539	70,884	54,495	48,979	-	0	-
Mean	8,262	175,337	183,599	168,297	158,804	76,310	61,148	33,365

Note:
Deerfield average begins in 1999

GMD3 System Optimization Study

Table 2
Annual Diversions, AF

Water Year	Amazon	Great Eastern	South Side	Farmers	Garden City	Total
1982	9,912	13,149	3,961	8,063	510	35,594
1983	20,559	32,533	19,413	22,765	2,590	97,860
1984	34,014	40,789	21,672	20,866	2,425	119,766
1985	34,402	26,240	20,210	16,126	2,095	99,072
1986	40,721	41,908	25,466	23,102	3,219	134,417
1987	37,839	19,591	21,668	20,390	2,791	102,279
1988	41,074	39,465	23,181	21,154	2,650	127,524
1989	21,924	19,004	7,234	13,145	1,736	63,042
1990	4,610	13,089	6,631	10,354	1,708	36,391
1991	5,504	15,630	4,379	8,303	1,410	35,227
1992	9,975	15,342	9,793	6,272	1,248	42,629
1993	8,132	18,107	9,241	14,650	1,293	51,424
1994	13,282	17,570	10,233	17,891	2,479	61,455
1995	35,951	20,732	13,551	22,437	3,132	95,803
1996	28,771	29,242	17,846	19,052	2,886	97,796
1997	29,925	19,355	13,672	20,085	2,700	85,737
1998	28,715	21,081	10,806	19,443	1,652	81,697
1999	26,551	19,037	11,619	13,825	1,365	72,397
2000						
2001						
2002	3,416	10,224	2,803	2,675	456	19,575
2003	-	10,260	-	-	-	10,260
2004	8,648	10,721	1,539	553	194	21,655
2005	13,880	24,480	4,888	6,681	206	50,134
2006	8,873	15,422	790	117	258	25,461
2007	31,066	4,444	8,406	14,326		58,241
2008	30,768	-	9,222	4,309		44,299
2009	31,895	-	11,823	9,540		53,257
2010	36,737	-	13,682	5,150		55,569
2011		-	6,088	2,015		8,102
Mean	22,116	17,765	11,065	12,260	1,696	63,809

Notes:

2008-2011 Great Eastern combined with Amazon

2007-2011 Garden City combined with Farmers

2000 & 2001 diversions removed due to incomplete data

GMD3 System Optimization Study
Table 3

Stream Loss Analysis, cfs/mile

Flow Range, cfs	Kendall to Deerfield Reach		Flow Range, cfs	Deerfield to Garden City Reach	
	Summer	Winter		Summer	Winter
0-100	1.6	1.7	0-100	2.5	3.5
100-200	2.6	0.8	100-200	5.4	3.3
200-450	4.3	0.2	200-450	2.5	2.1

Table 4

Summary of ADS Yields

(Acre-feet)

		Increased Diversions to Farmers Ditch					
		South Side ADS		Great Eastern ADS		River Channel	
Water Year	Historical Farmers Diversion	23% loss	32% loss	35 % loss	47 % loss	loss @3 cfs /mile	loss @ 4.5 cfs/mile
1982	8,573	4,531	3,980	3,764	2,801	1,369	2,053
1983	24,816					2,291	3,436
1984	23,736					2,737	4,106
1985	18,119						
1986	26,063						
1987	23,207						
1988	23,719						
1989	14,904	6,306	5,102	4,693	2,786	3,184	4,775
1990	12,206	734	4	(240)	(1,756)	3,184	4,775
1991	9,660	7,818	6,533	6,105	3,897	2,722	4,084
1992	7,537	5,412	4,657	4,406	3,399	2,737	4,106
1993	15,896	2,472	2,107	1,985	1,426	2,276	3,414
1994	20,587					3,184	4,775
1995	25,458						
1996	22,045						
1997	22,788						
1998	21,095						
1999	15,190						
2000							
2001							
2002	3,129	10,123	8,671	8,187	6,250	1,369	2,053
2003	2	4,863	4,294	4,105	3,347	-	-
2004	747	13,904	12,949	12,538	10,342	1,830	2,745
2005	6,887	6,941	5,949	5,533	3,867	1,815	2,722
2006	375	7,887	7,056	6,778	5,669	446	669
2007	14,326					3,184	4,775
2008	4,309	8,438	7,468	7,124	5,628	2,737	4,106
2009	9,540	7,146	6,167	5,722	3,768	3,184	4,775
2010	5,150	2,291	1,517	1,259	228	1,369	2,053
2011	2,015	7,301	6,861	6,714	6,127	922	1,383
Average							
All yrs	13,646	3,434	2,976	2,810	2,064	1,448	2,172
Operation yrs	6,032	6,411	5,554	5,245	3,852	2,134	3,200
% increase		106%	92%	87%	64%	35%	53%

Notes
Includes diversions for the Garden City Ditch

2000 and 2001 excluded due to incomplete record
ADS Operational: 15 of 28 years
River channel used 19 of 28 years

GMD3 System Optimization Study
Table 5

Bear Creek Valley Recharge Diversion
Divertable Flow with 700 cfs Capacity Restriction
Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	2,511	-	-	213	-	-	990	10,779	-	-	-	-	14,493
1986	2,136	-	-	-	-	-	-	-	1,202	1,160	1,118	-	5,616
1987	7,661	2,729	-	425	6,183	31,001	29,467	40,836	7,878	-	-	-	126,180
1988	4,280	6,612	3,128	2,888	-	-	-	-	-	-	718	-	17,624
1989	200	-	-	438	-	-	-	-	-	-	-	-	638
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,722	41,613	5,860	-	-	49,195
1996	3,362	1,790	202	1,276	222	-	4,711	1,943	931	2,245	-	-	16,681
1997	8,784	8,330	6,432	409	-	-	-	-	-	13,169	-	-	37,124
1998	17,384	22,514	42,114	24,509	26,311	18,067	798	-	1,267	4,656	-	-	157,620
1999	11,098	4,018	5,298	2,143	2,924	-	40,849	41,208	6,413	14,831	-	-	128,782
2000	11,411	9,116	3,459	12,045	19,133	-	-	-	833	-	-	-	55,997
2001	6,750	2,702	-	615	200	-	-	290	-	-	-	-	10,556
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	5,984	-	-	-	-	-	-	-	5,984
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	2,519	1,927	2,021	1,499	2,032	1,636	2,561	3,226	2,005	1,397	61	-	20,883
Max	17,384	22,514	42,114	24,509	26,311	31,001	40,849	41,208	41,613	14,831	1,118	-	157,620

Table 6a

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 5: South Side Return to Farmers Headgate

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 19,900	1	**$ 19,900**	Assume as 10% of listed items	n/a
2	**Ditch Excavation nad Berms**	CY	$ 6.00	10,600	**$ 63,600**	Unit price work-up, attached	
3	**Ditch Lining**	SF	$ 2.50	-	**$ -**	May be required at a future time	From Civil 3D, see spreadsheet, attached.
5	**Cast-In-Place Concrete Box Culvert**	CY	$ 700.00		**$ -**	Maybe be required in upper sections; but not included at this time.	From Civil 3D, see spreadsheet, attached.
6	**Release to River and Diversion from River**	LS	$ 100,000	1	**$ 100,000**		
7	**Erosion & Sediment Control**	LS	$ 20,000.00	1	**$ 20,000**	Assume extra work around Arkansas River crossing	
8	**Dewatering**	LS	$ 15,000.00	1	**$ 15,000**	Assume extra work around Arkansas River crossing	
	Subtotal Direct Construction Cost (DCS)				**$218,500**		
	Contingency Allowance	30% of DCS			$65,600	n/a	n/a
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$284,100**		

Note: Cost shown above excludes an inverted siphon crossing of the Arkansas River. If this siphon were added to this alternative, the total cost with increase by $1.9 million to $2.18 million.

Table 6b

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 1A: Great Eastern Ditch Bypass to Farmers Headgate

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 449,700	1	**$ 449,700**	Assume as 10% of listed items	n/a
2	**Trench Excavation**	CY	$ 6.00	70,000	**$ 420,000**	Unit price work-up, attached	
3	**Furnish and Install 7' Diameter RCP**	LF	$ 300.00	13,000	**$ 3,900,000**	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
4	**Pipe Bedding and Trench Backfill**	CY	$ 4.00	44,000	**$ 176,000**	Unit price work-up, attached	
5	**Furnish and Install Precast Vaults**	EACH	$ 16,000	12	**$ 192,000**	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
6	**Pipe Berm Backfill**	CY	$ 10.00	29,000	**$ 290,000**	Price for Pipe Backfill + Haul to berm location	From Civil 3D, see spreadsheet, attached.
7	**New Drop/Diversion Structure**						
	a Excavation and Backfill	CY	$ 10.00	170	$ 1,700	Unit price work-up, attached	assume 20' deep x 15 x 15 excavation
	b Reinforced Concrete	CY	$ 700.00	60	$ 42,000	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
	Subtotal				**$ 43,700**		
8	**New Outlet Structure**						
	a Excavation and Backfill	CY	$ 10.00	170	$ 1,700	Unit price work-up, attached	assume 20' deep x 15 x 15 excavation
	b Reinforced Concrete	CY	$ 700.00	50	$ 35,000	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
	Subtotal				**$ 36,700**		
9	**Erosion & Sediment Control**	LS	$ 10,000.00	1	**$ 10,000**		
10	**Dewatering**	LS	$ 25,000.00	1	**$ 25,000**		
	Subtotal Direct Construction Cost (DCS)				**$4,947,100**		
	Contingency Allowance	30% of DCS			$1,484,100	n/a	n/a
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$6,431,200**		

Table 6c

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 1B: Great Eastern Ditch to Farmers Ditch

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 54,400	1	**$ 54,400**	Assume as 10% of listed items	n/a
2	**Trench Excavation**	CY	$ 6.00	9,000	**$ 54,000**	Unit price work-up, attached	
3	**Furnish and Install 4' Diameter PVC**	LF	$ 150.00	2,700	**$ 405,000**	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
4	**Pipe Bedding and Trench Backfill**	CY	$ 4.00	7,200	**$ 28,800**	Unit price work-up, attached	
5	**Furnish and Install 96-inch-diameter Manholes**	EACH	$ 8,500	2	**$ 17,000**	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
6	**Pipe Berm Backfill**	CY	$ 10.00	2,200	**$ 22,000**	Price for Pipe Backfill + Haul to berm location	From Civil 3D, see spreadsheet, attached.
7	**New Drop/Diversion Structure**						
	a Excavation and Backfill	*CY*	$ 10.00	170	$ 1,700	Unit price work-up, attached	assume 20' deep x 15 x 15 excavation
	b Reinforced Concrete	*CY*	$ 700.00	60	$ 42,000	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
	Subtotal				**$ 43,700**		
8	**New Outlet Structure**						
	a Excavation and Backfill	*CY*	$ 10.00	170	$ 1,700	Unit price work-up, attached	assume 20' deep x 15 x 15 excavation
	b Reinforced Concrete	*CY*	$ 700.00	50	$ 35,000	Unit price work-up, attached	From Civil 3D, see spreadsheet, attached.
	Subtotal				**$ 36,700**		
9	**Erosion & Sediment Control**	LS	$ 10,000	1	**$ 10,000**		
10	**Dewatering**	LS	$ 10,000	1	**$ 10,000**		
	Subtotal Direct Construction Cost (DCS)				**$598,800**		
	Contingency Allowance	30% of DCS			$179,600	n/a	n/a
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$778,400**		

Table 6d

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 2: "River Restoration"Lined Bypass Channel

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 120,000	1	**$ 120,000**	Assume as 10% of listed items	n/a
2	**Site Clearing/Preparation**	SY	$ 2.00	11,800	**$ 23,600**	Assumed	From rough layout
3	**Excavation and Berm**	CY	$ 6.00	67,000	**$ 402,000**	Unit price work-up, attached	From rough layout
4	**Dewatering**	LS	$ 5,000	1	**$ 5,000**	Unit price work-up, attached	From rough layout
5	**Ditch Lining**	SF	$ 1.50	385,000	**$ 577,500**	Unit price work-up, attached	From rough layout
7	**Erosion & Sediment Control**	LS	$ 5,000	1	**$ 5,000**		
8	**Diversion and Gated Intake Structure**	LS	$ 175,000	1	**$ 175,000**	Conceptual workup	
9	**Outlet to River**	LS	$ 15,000	1	**$ 15,000**	RAW estimate; riprap at $50/CY	
	Subtotal Direct Construction Cost (DCS)				**$1,323,100**		
	Contingency Allowance	30% of DCS			$397,000		
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$1,720,100**		

Table 6e

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 3: Bear Valley Recharge Point of Diversion #2 to Discharge Point #2

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 562,000	1	**$ 562,000**	Assume as 10% of listed items	n/a
2	**Site Clearing/Preparation**	SY	$ 1.00	340,000	**$ 340,000**	Assumed	From rough layout
3	**Excavation and Berm**	CY	$ 6.00	820,000	**$ 4,920,000**	Unit price work-up, attached	From rough layout
4	**Drop Structures**	LS	$ 50,000	-	**$ -**	Not required for Option 2	
5	**Dewatering**	LS	$ 30,000	1	**$ 30,000**	Assumed	From rough layout
6	**Erosion & Sediment Control**	LS	$ 15,000	1	**$ 15,000**	Assumed	
7	**Diversion and Gated Intake Structure**	LS	$ 310,000	1	**$ 310,000**	Conceptual workup	
	Subtotal Direct Construction Cost (DCS)				**$6,177,000**		
	Contingency Allowance	30% of DCS			$1,853,000		
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$8,030,000**		

Table 6f

Opinion of Probable Construction Cost

Southwest Kansas Groundwater Management District 3

Alternative 8: South Side Sprinkler Service Pit (Typical)

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 36,000	1	**$ 36,000**	Assume as 10% of listed items	n/a
2	**Site Clearing/Preparation**	SY	$ 2.00	4,000	**$ 8,000**	Assumed	From rough layout
3	**Excavation and Berm Fill**	CY	$ 6.00	3,350	**$ 20,100**	Unit price work-up, attached	From rough layout
4	**Pit Lining (Assumed not Required**	SF	$ 1.50	-	**$ -**	Unit price work-up, attached	From rough layout
5	**Pumping Facility (70 HP)**	LS	$ 80,000	1	**$ 80,000**	Conceptual workup	
6	**Erosion & Sediment Control**	LS	$ 15,000	1	**$ 15,000**	Assume extra work around Arkansas River crossing	
7	**Inlet and Outlet Structure/Piping**	LS	$ 8,000	2	**$ 16,000**	Conceptual workup	
8	**Conveyance Pipeline - 10-in PVC**	FT	$ 40.00	5,300	**$ 212,000**	Means	
9	**Erosion & Sediment Control**	LS	$ 5,000	1	**$ 5,000**	Assumed	
10	**Dewatering**	LS	$ 5,000	1	**$ 5,000**	Assumed	
	Subtotal Direct Construction Cost (DCS)				**$397,100**		
	Contingency Allowance	30% of DCS			$119,000		
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$516,100**		

Table 6g

Opinion of Probable Construction Cost

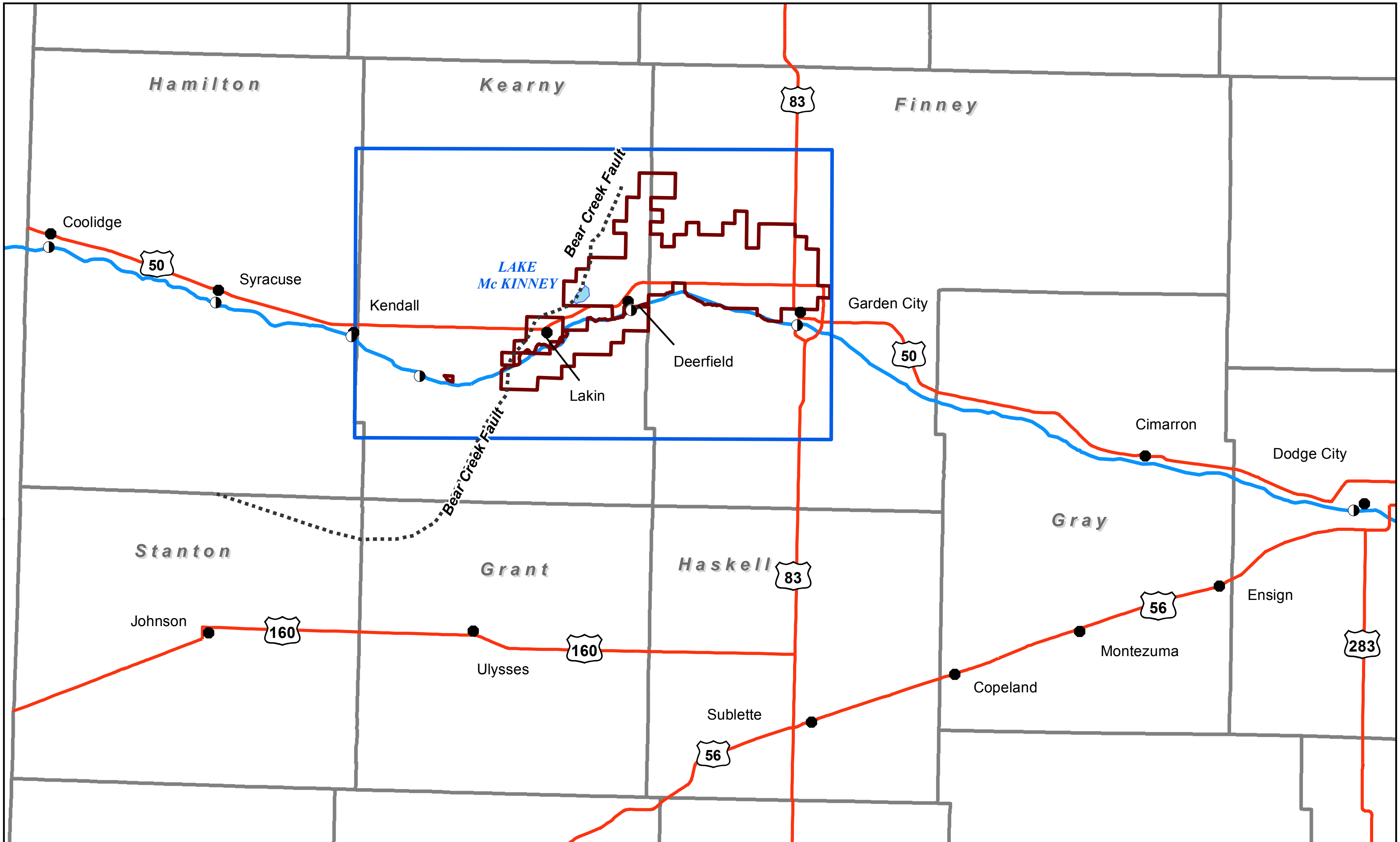
Southwest Kansas Groundwater Management District 3

Alternative 4: Hydropower Development on the Frontier Ditch Wasteway

No.	Item Description	Unit	Unit Price	Qty.	Amount	Basis of Estimate: Unit Price	Basis of Estimate: Quantity
1	**Mobilization and Demobilization**	LS	$ 2,000	1	**$ 2,000**	Assume as 10% of listed items	n/a
2	**Gated Intake at Dirch Structure**	LS	$ 2,000	1	**$ 2,000**	Assumed	
3	**24-inch Penstock**	FT	$ 80.00	75	**$ 6,000**	Assume DI pipe/buried	
4	**5 kW Turbine and Generator**	kW	$ 1,500.00	5	**$ 7,500**	Estimate by RAW ; experience	
5	**Power Unit Civil**	LS	$ 2,000.00	1	**$ 2,000**	Assumed	
6	**Electrical Connection**	LS	$ 3,000.00	1	**$ 3,000**	Assumed. Electrical line is relatively close.	
	Subtotal Direct Construction Cost (DCS)				**$22,500**		
	Contingency Allowance	30% of DCS			$7,000		
	Opinion of Probable Construction Cost (OPCC) -- 2014				**$29,500**	$5,900	/kW; Cost per installed kW seems reasonable

Cost per kW **$5,900**

Figures



GMD3 System Optimization Study

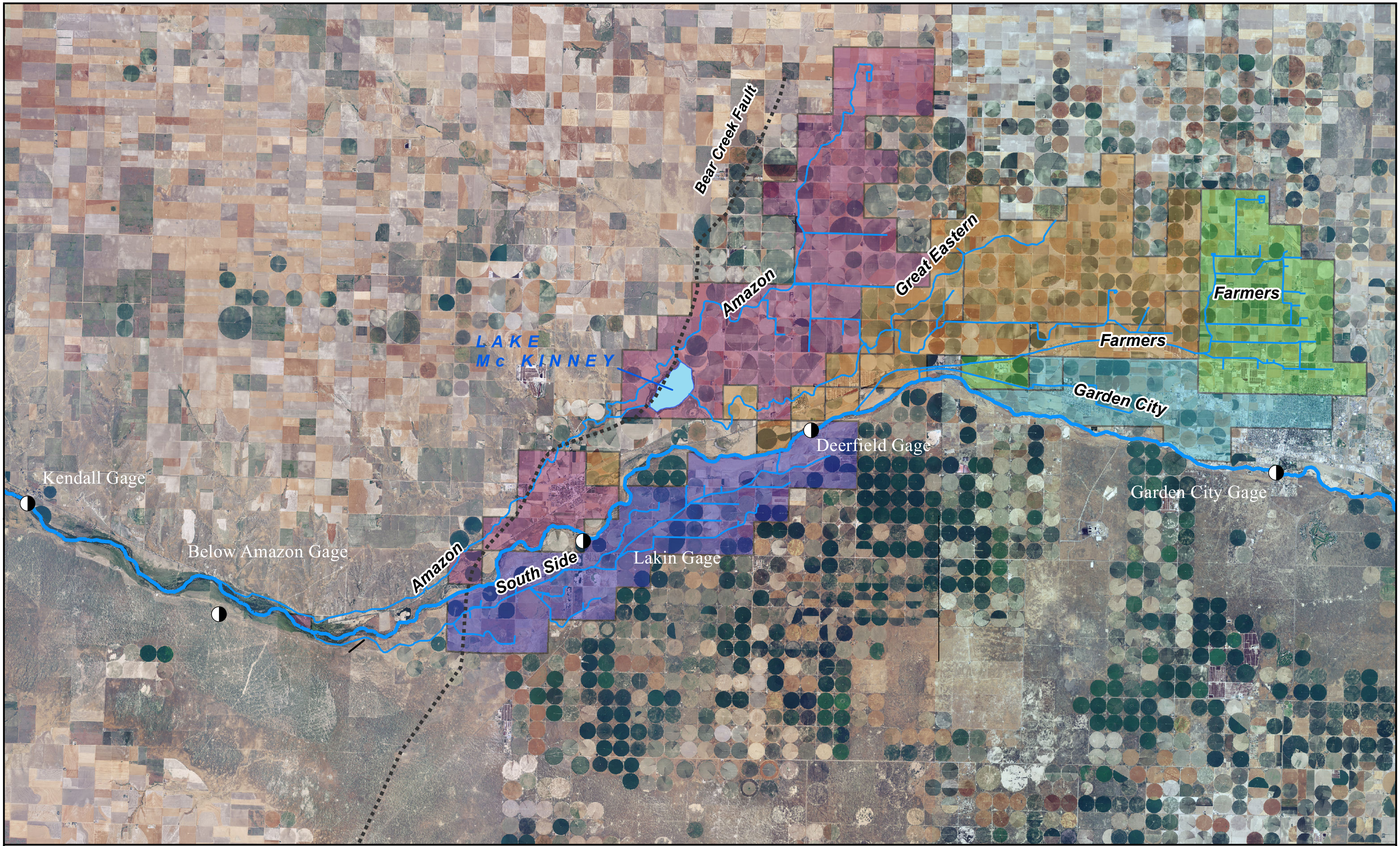
Figure 1
General Location Map

Project Area
Service Area
Arkansas River
Streamflow Gages

Miles
5 2.5 0 5 10
Approximate Scale = 1:700,000

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

09/30/2014



GMD3 System Optimization Study

Figure 2

Project Study Area

Miles 2 1 0 2 4

Approximate Scale = 1:250,000

Ditch Service Areas

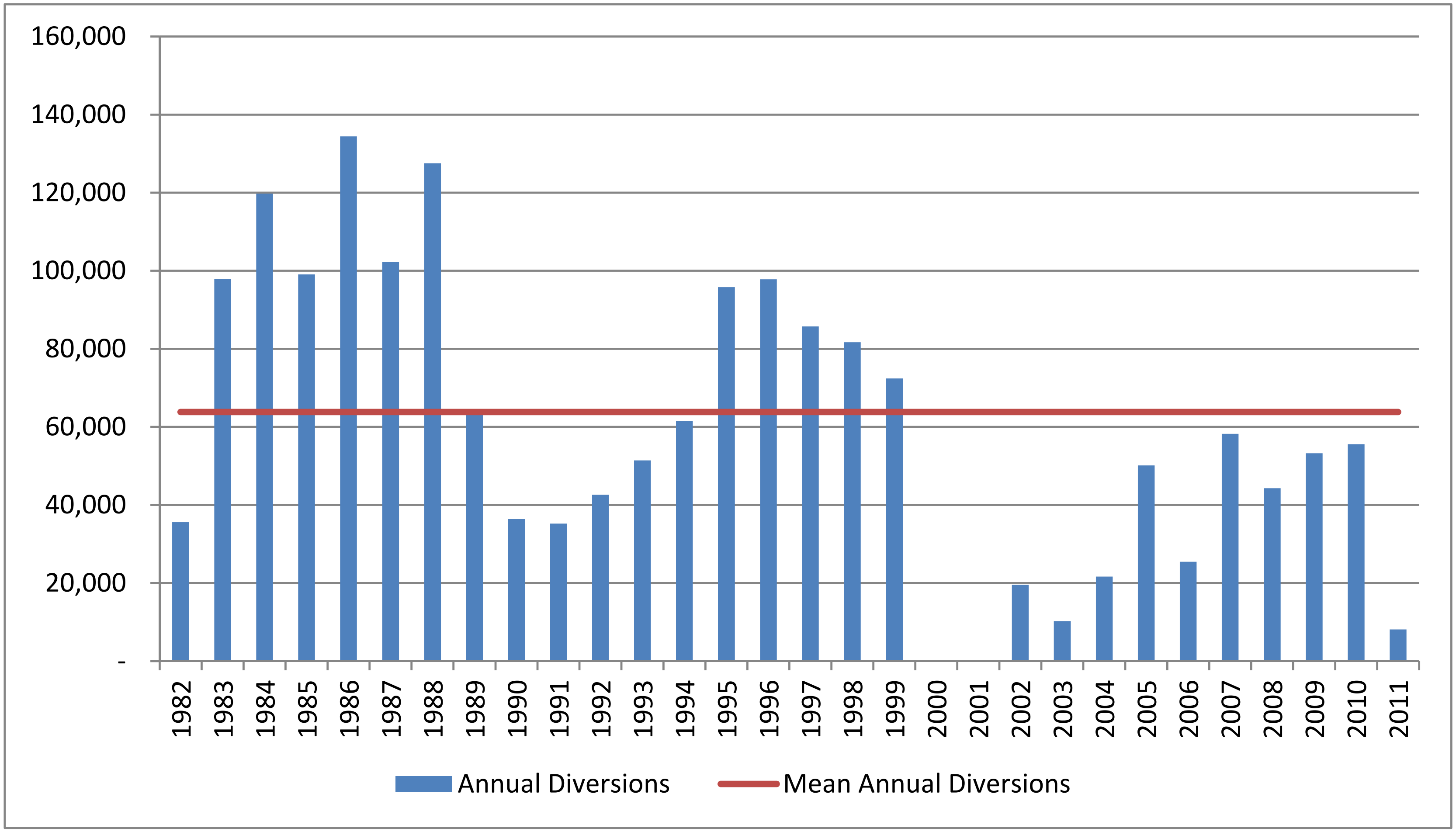
- Amazon
- Farmers
- Garden City
- Great Eastern
- South Side

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

09/30/2014

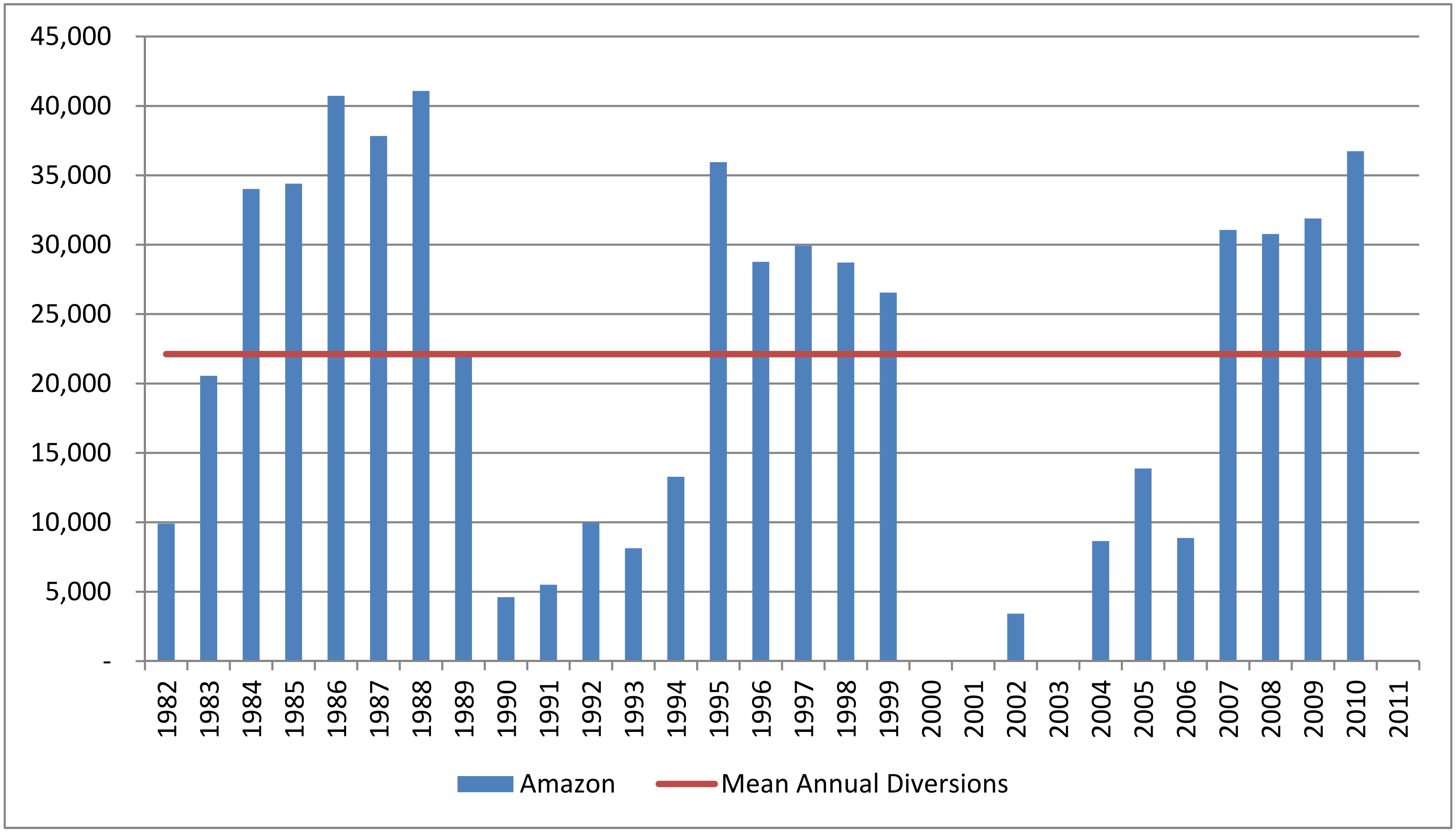
GMD3 System Optimization Study
Figure 3a

Total Annual Diversions, AF



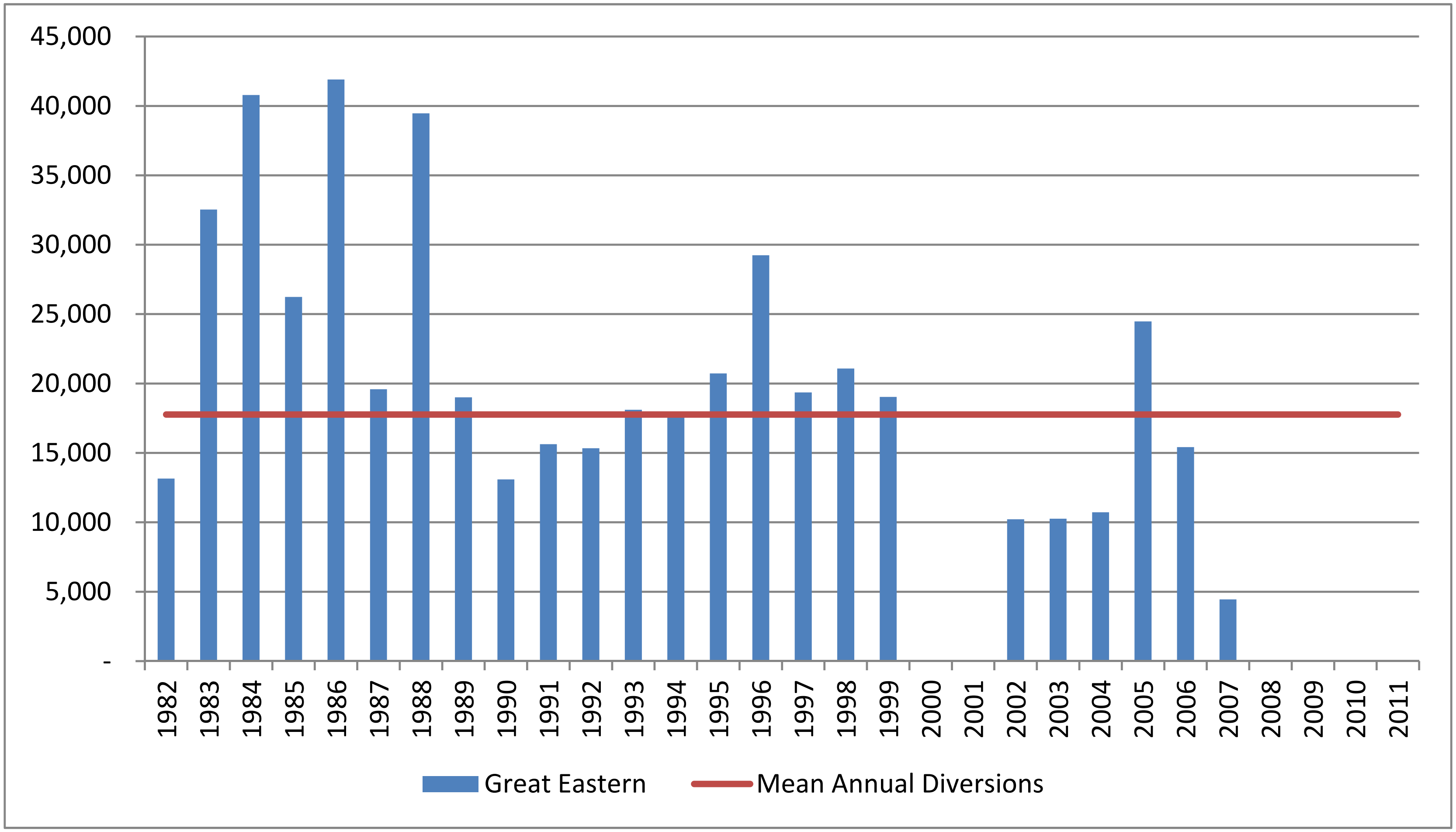
GMD3 System Optimization Study
Figure 3b

Amazon Ditch Annual Diversions, AF



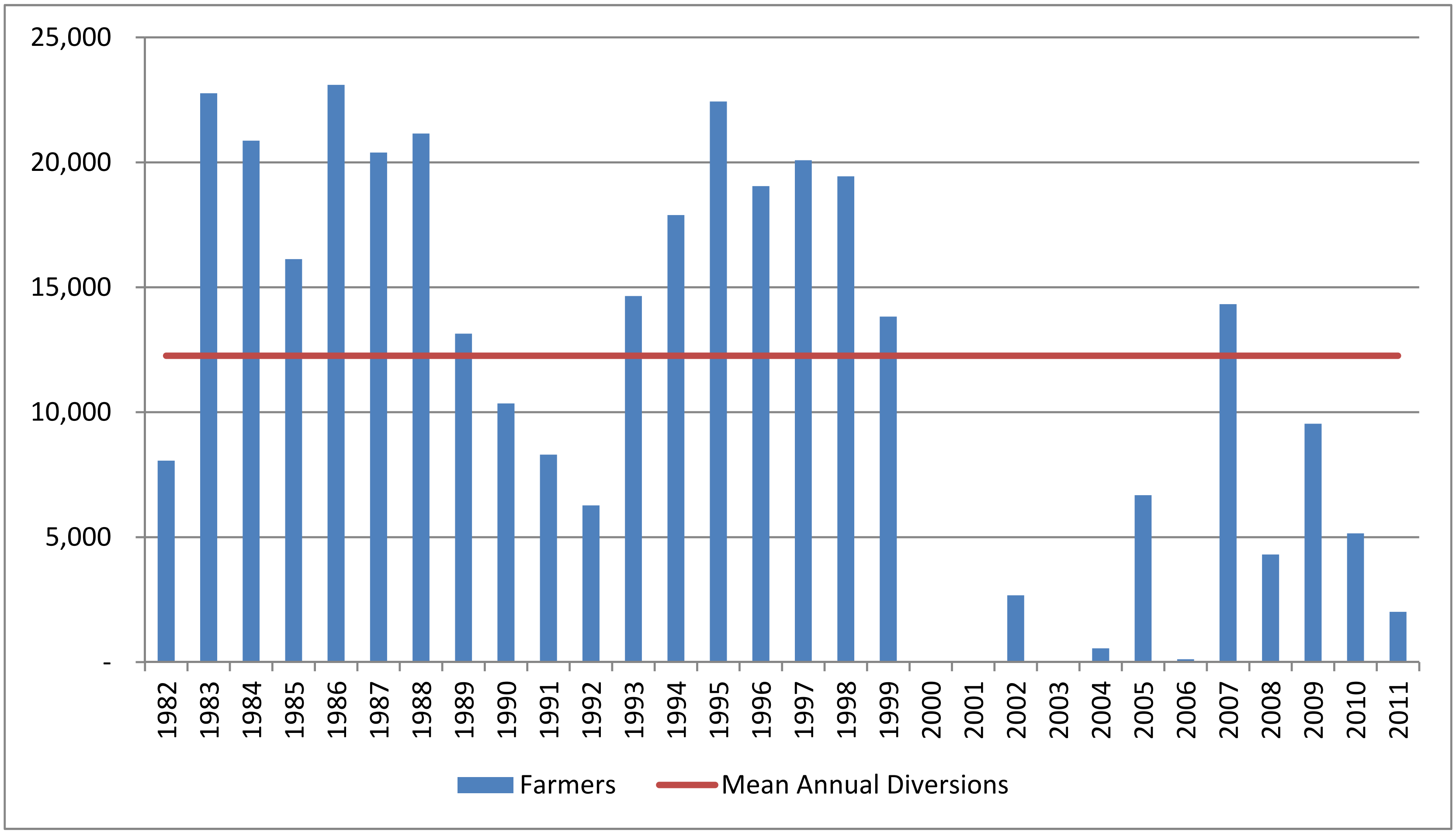
GMD3 System Optimization Study
Figure 3c

Great Eastern Ditch Annual Diversions, AF



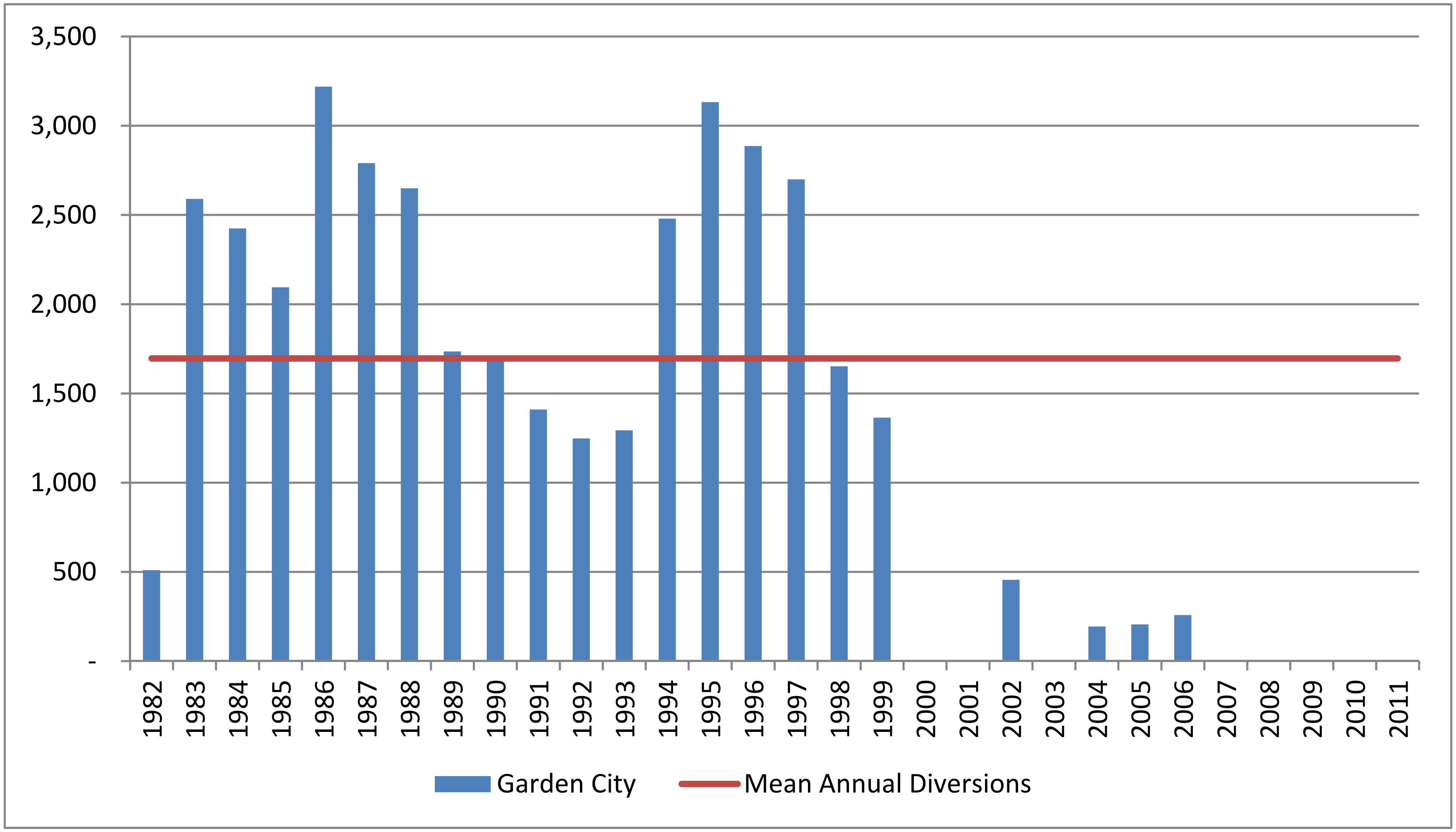
GMD3 System Optimization Study
Figure 3d

Farmers Ditch Annual Diversions, AF

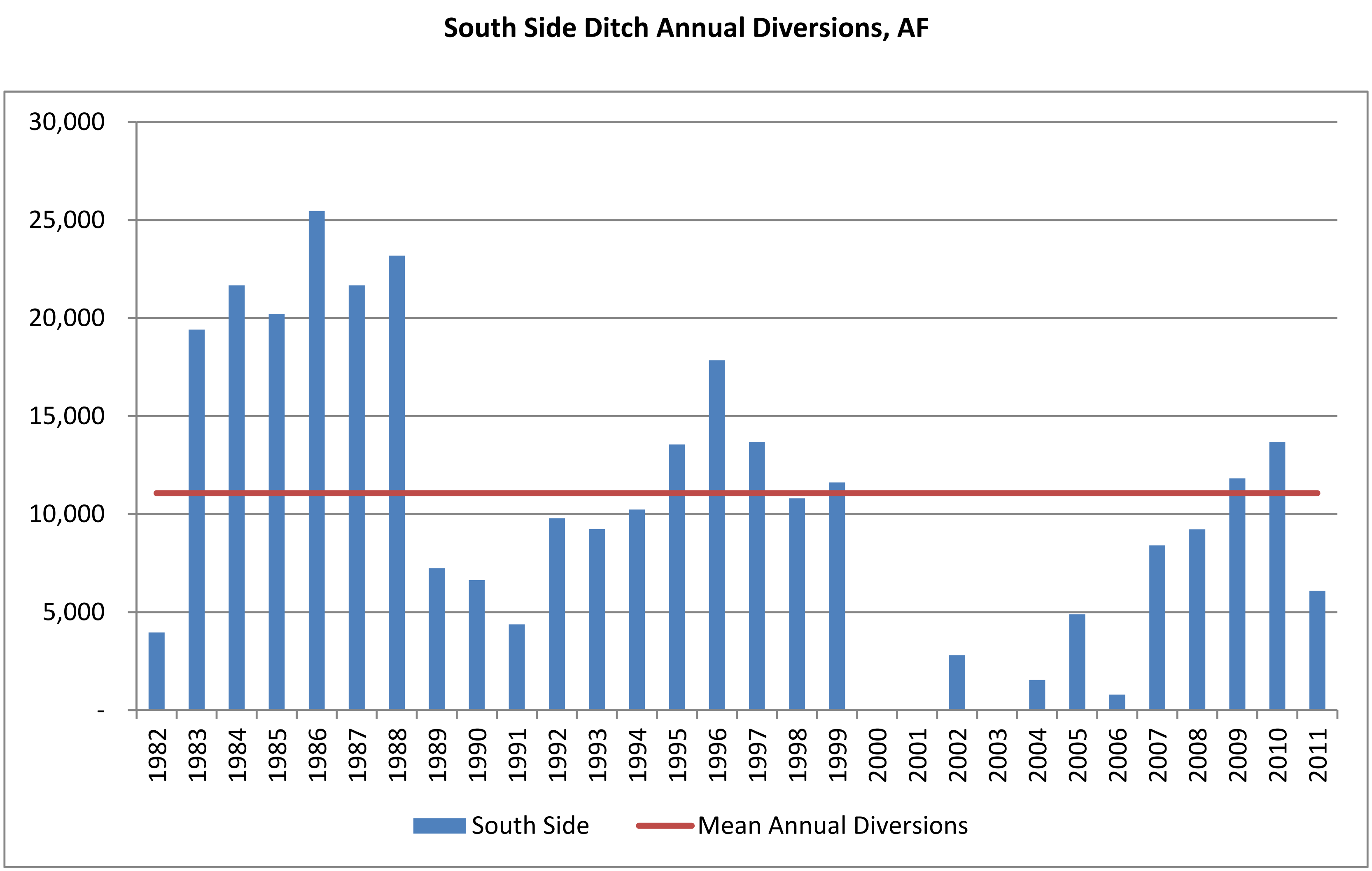


GMD3 System Optimization Study
Figure 3e

Garden City Ditch Annual Diversions, AF



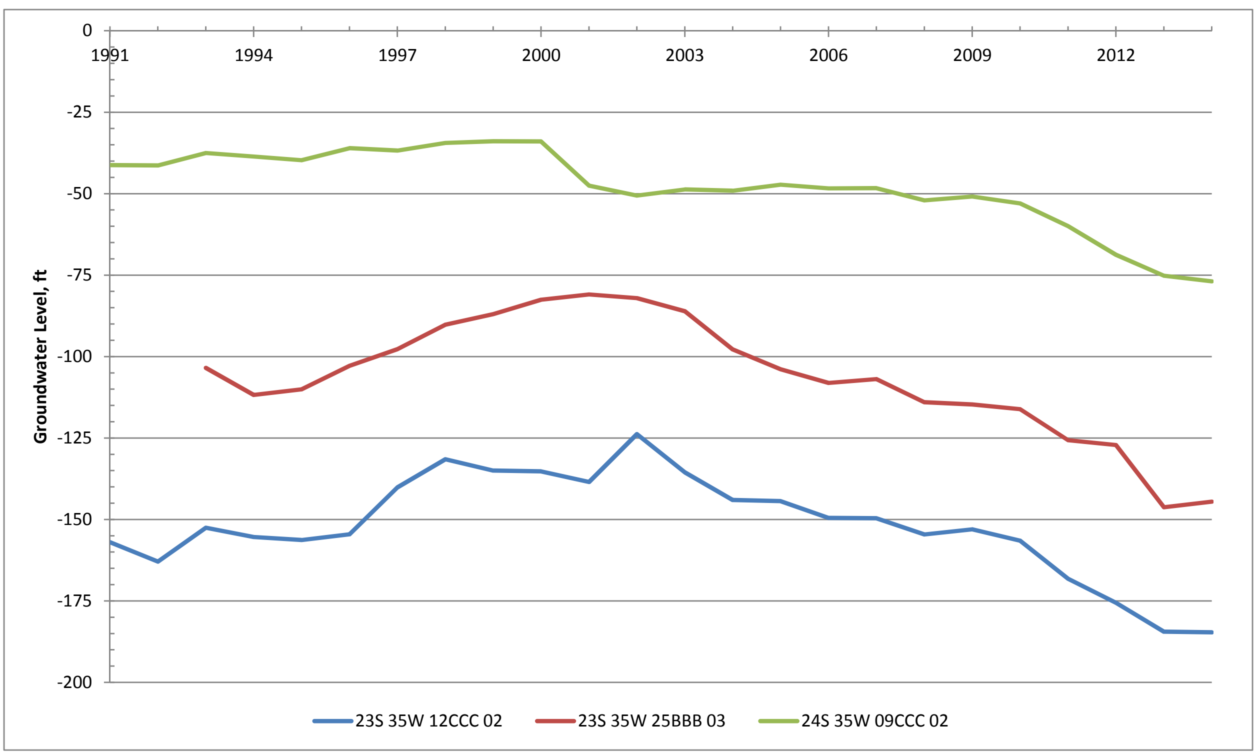
GMD3 System Optimization Study
Figure 3f



GMD3 System Optimization Study
Figure 4a

Wells Examined in 2002 KGS Report
Yearly Average Groundwater Level, feet

Year	23S 35W 12CCC 02	23S 35W 25BBB 03	24S 35W 09CCC 02
1991	-157		-41
1992	-163		-41
1993	-153	-103	-37
1994	-155	-112	-39
1995	-156	-110	-40
1996	-155	-103	-36
1997	-140	-98	-37
1998	-132	-90	-34
1999	-135	-87	-34
2000	-135	-83	-34
2001	-138	-81	-48
2002	-124	-82	-51
2003	-136	-86	-49
2004	-144	-98	-49
2005	-144	-104	-47
2006	-150	-108	-48
2007	-150	-107	-48
2008	-155	-114	-52
2009	-153	-115	-51
2010	-157	-116	-53
2011	-168	-126	-60
2012	-176	-127	-69
2013	-184	-146	-75
2014	-185	-144	-77
Average	-152	-106	-48

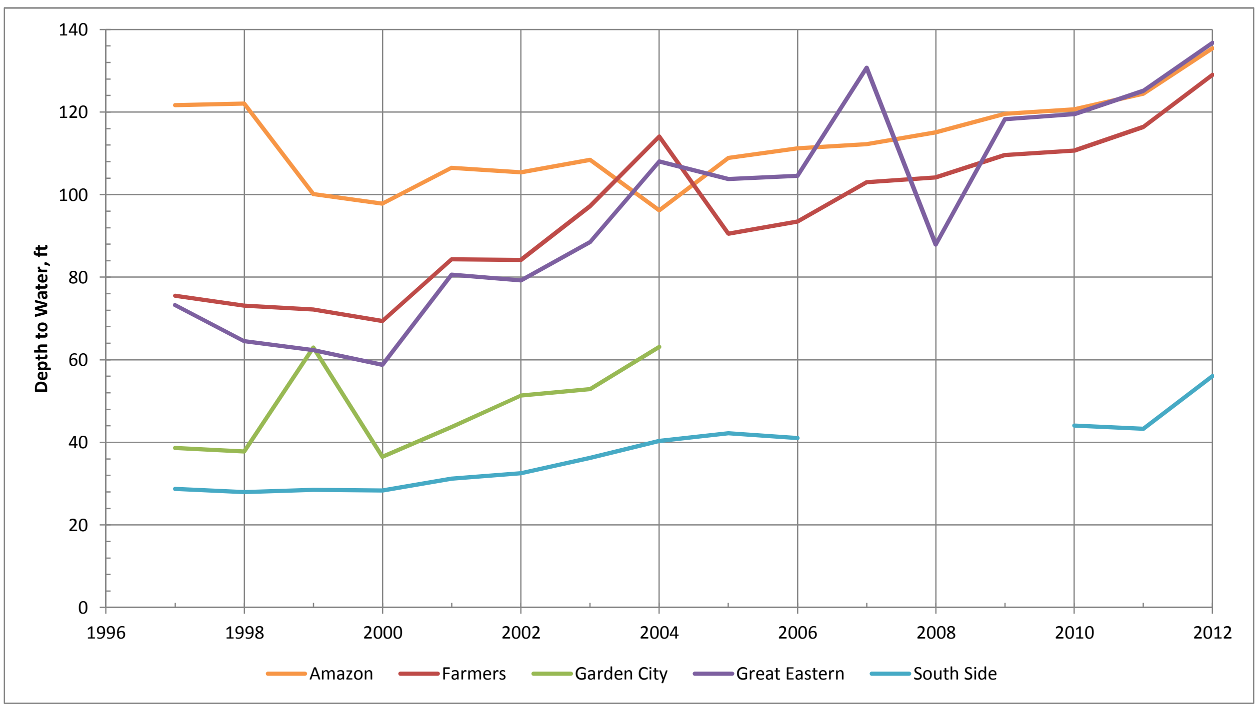


Note: Wells located in Amazon Ditch Service Area

Source: Figure 8 of KGS Ground-Water Recharge in the Upper Arkansas River Corridor in Southwest Kansas Report

GMD3 System Optimization Study
Figure 4b
Average Water Level by Service Area, feet

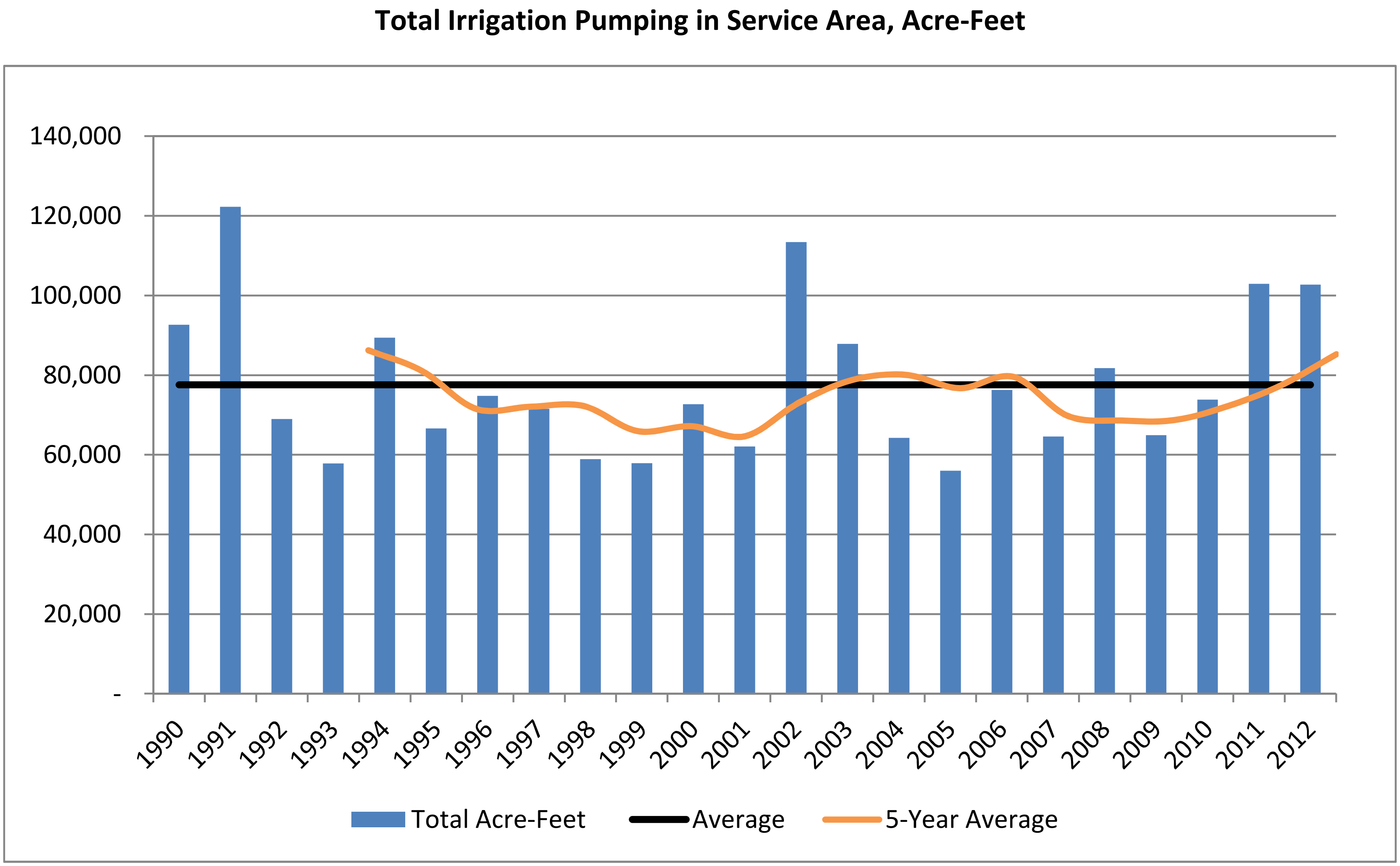
Year	Amazon		Farmers		Garden City		Great Eastern		South Side	
	Depth to Water	Num. of Readings	Depth to Water	Num. of Readings	Depth to Water	Num. of Readings	Depth to Water	Num. of Readings	Depth to Water	Num. of Readings
1997	122	3	76	3	39	3	73	5	29	1
1998	122	3	73	3	38	3	64	4	28	1
1999	100	3	72	4	63	4	62	4	28	2
2000	98	5	69	3	36	3	59	5	28	1
2001	106	3	84	2	44	1	81	6	31	1
2002	105	3	84	2	51	2	79	6	33	1
2003	108	3	97	2	53	1	89	6	36	1
2004	96	4	114	1	63	2	108	5	40	1
2005	109	5	91	3		0	104	5	42	1
2006	111	4	93	3	55	2	105	5	41	1
2007	112	5	103	3		0	131	4		1
2008	115	5	104	3		0	88	5		
2009	120	5	110	3	101	1	118	5		
2010	121	5	111	3		0	120	5	44	1
2011	124	5	116	3		0	125	5	43	1
2012	135	5	129	3		0	137	5	56	1
Averages										
Overall	113		95		54		96		37	
1997-2004	107		84		48		77		32	
2005-2012	118		107		78		116		45	



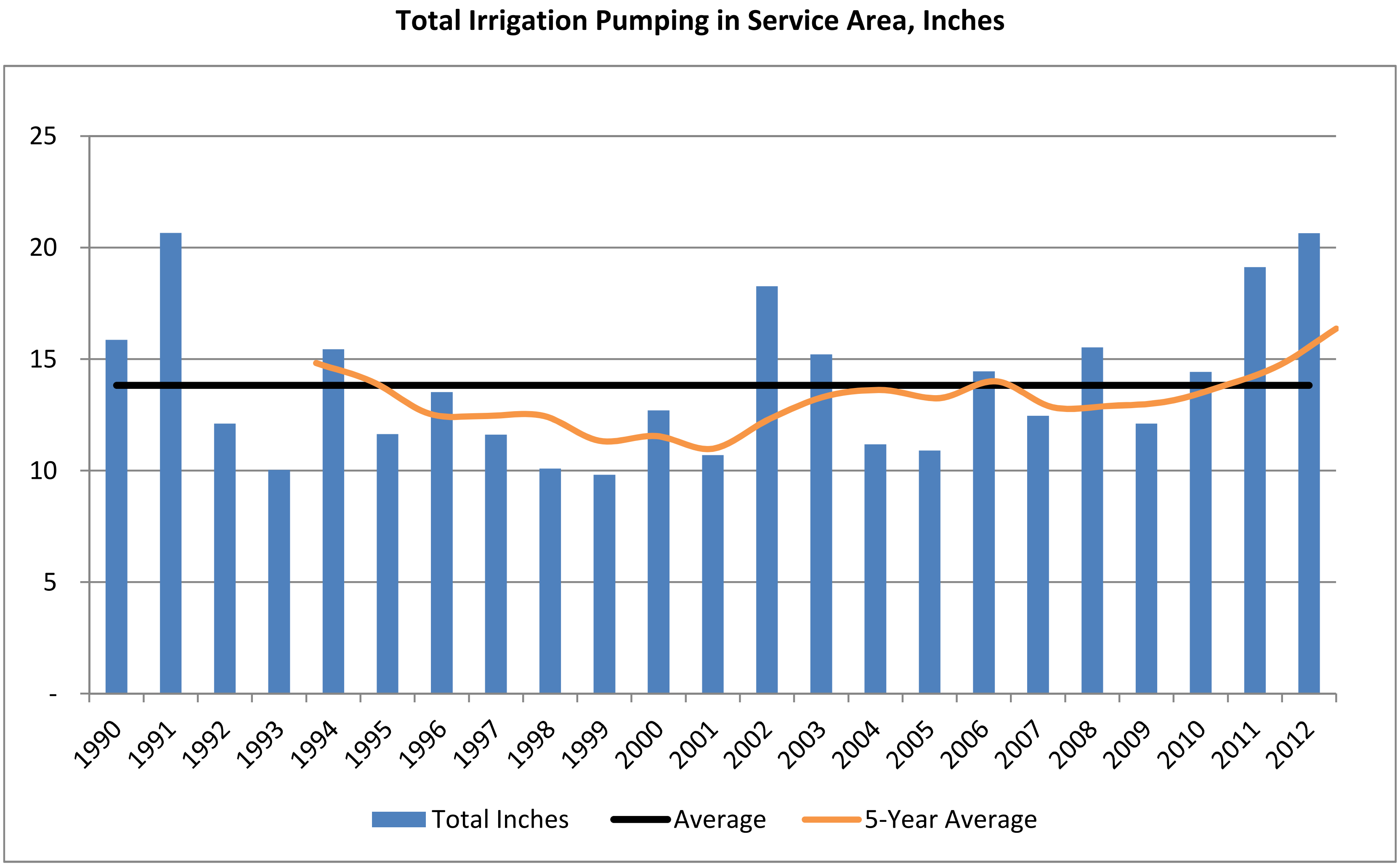
Note: Blanks indicate no data was available for that service area

Source: Kansas Geological Survey

GMD3 System Optimization Study
Figure 5a

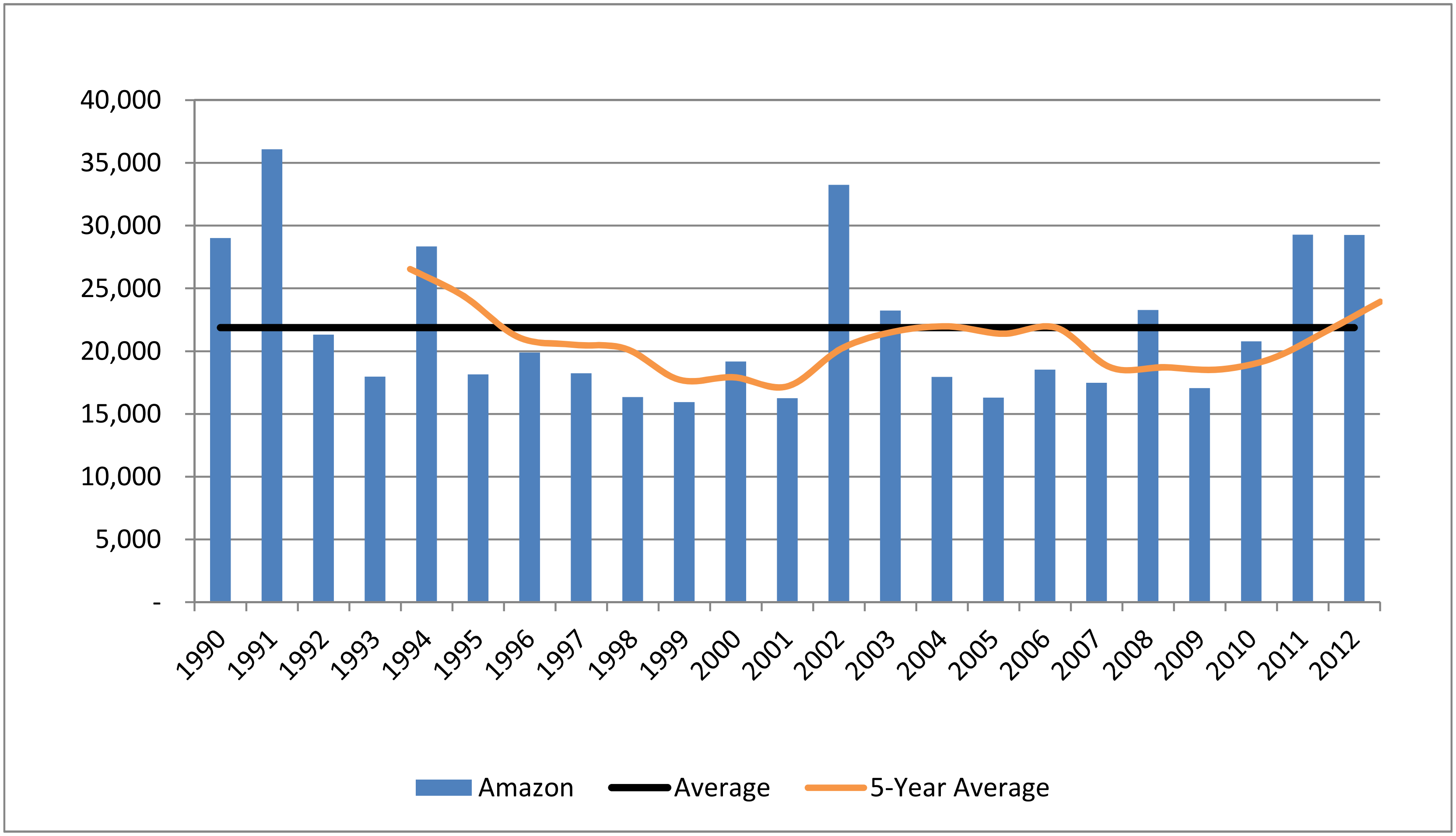


GMD3 System Optimization Study
Figure 5b

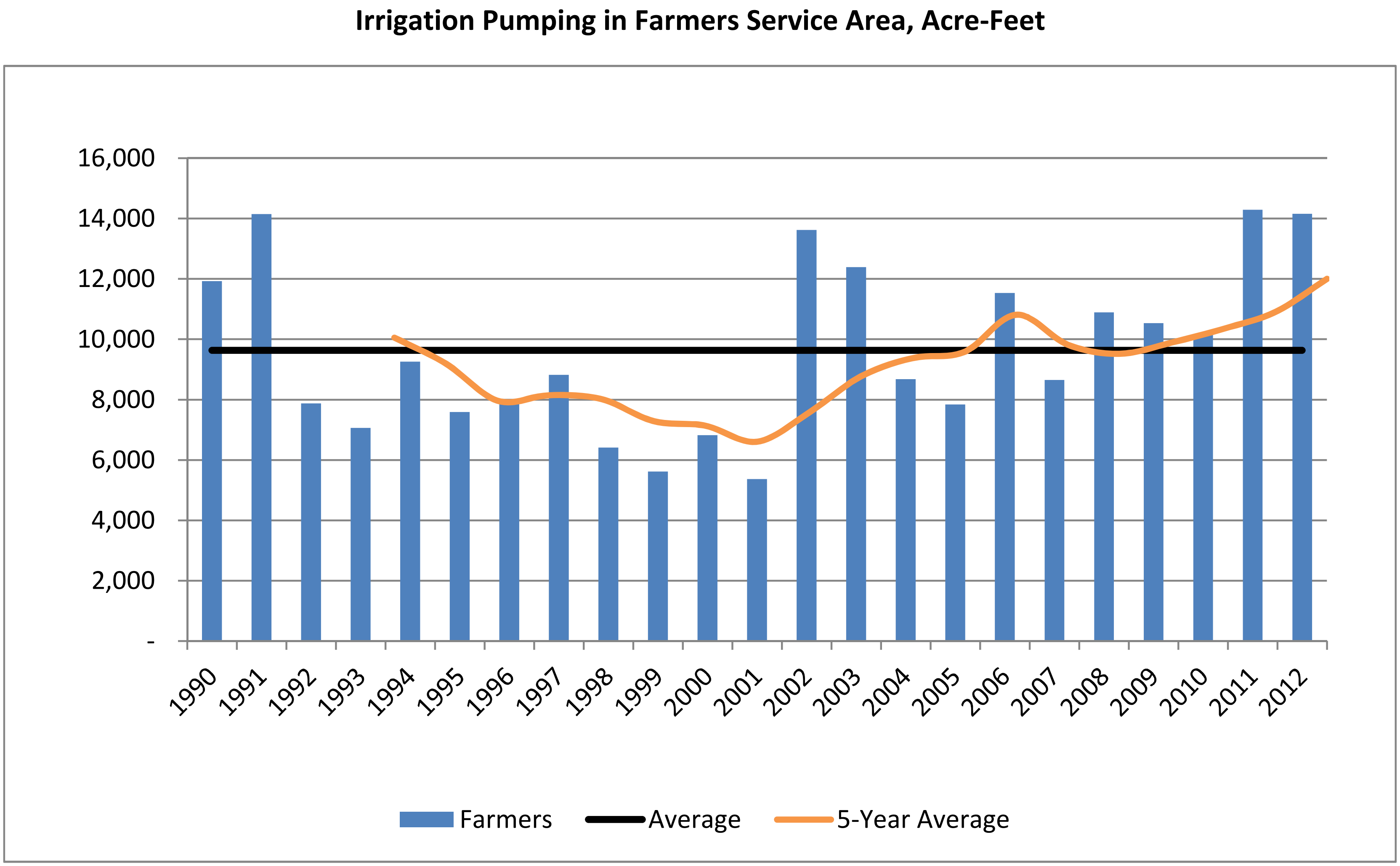


GMD3 System Optimization Study
Figure 5c

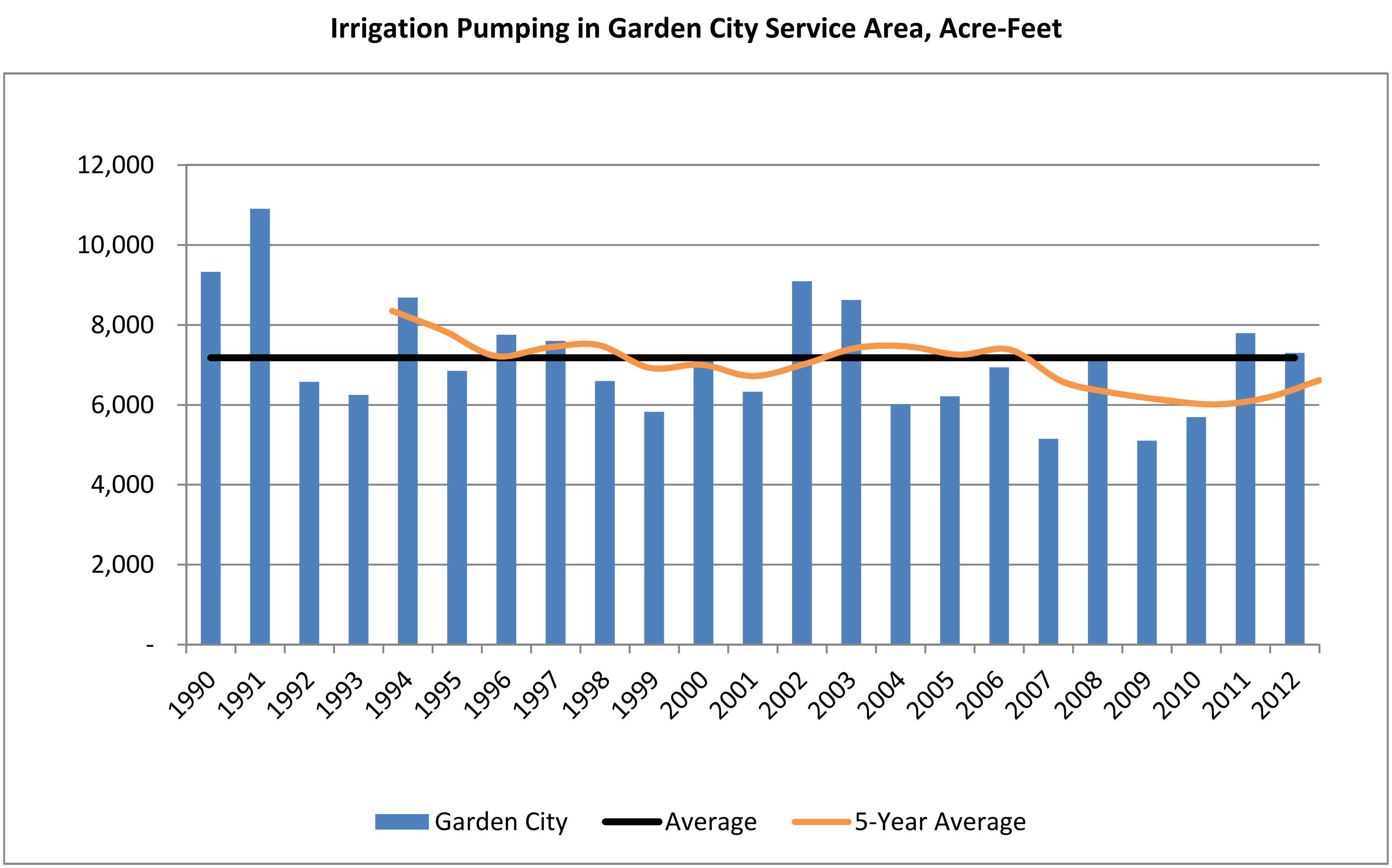
Irrigation Pumping in Amazon Service Area, Acre-Feet



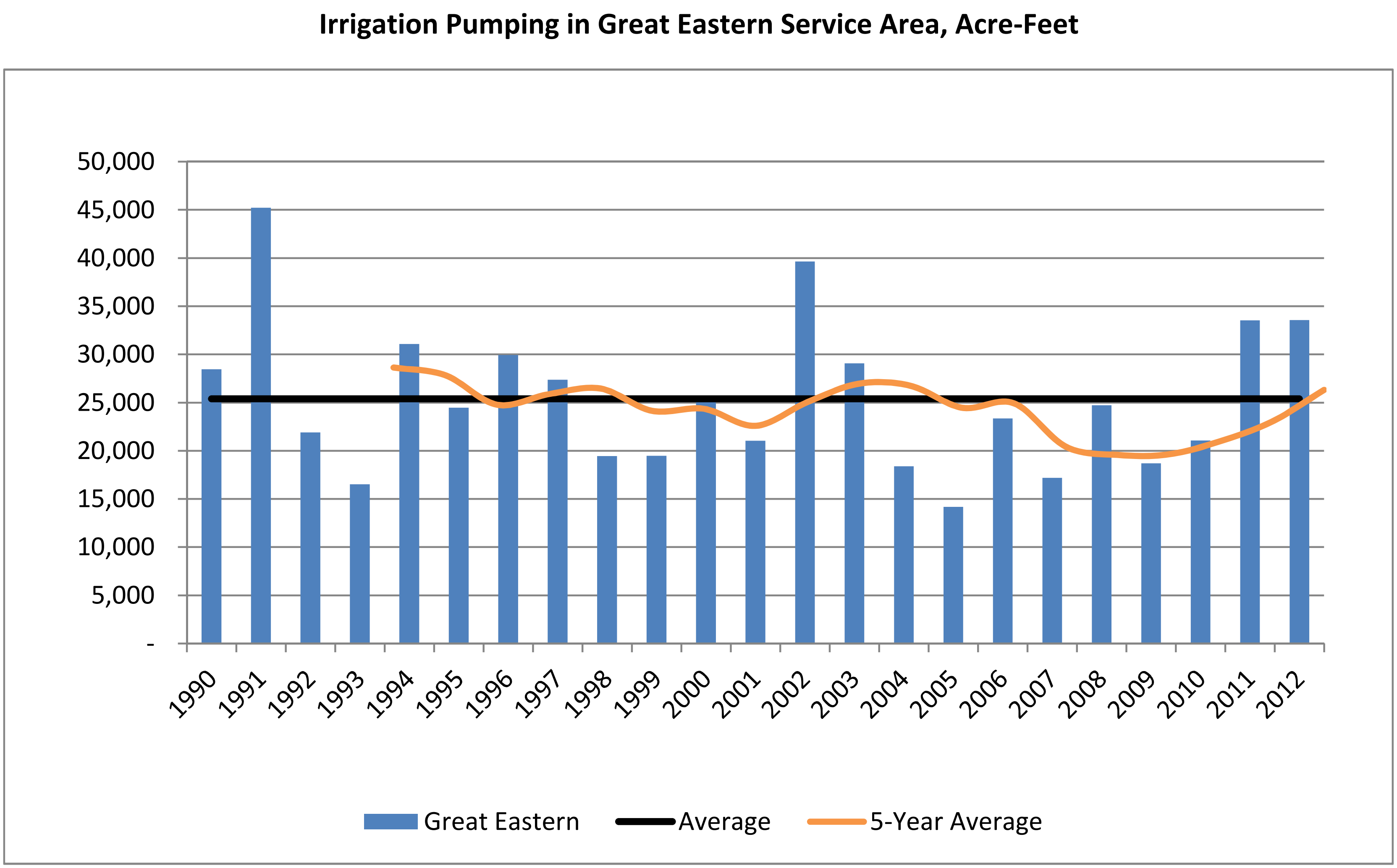
GMD3 System Optimization Study
Figure 5d



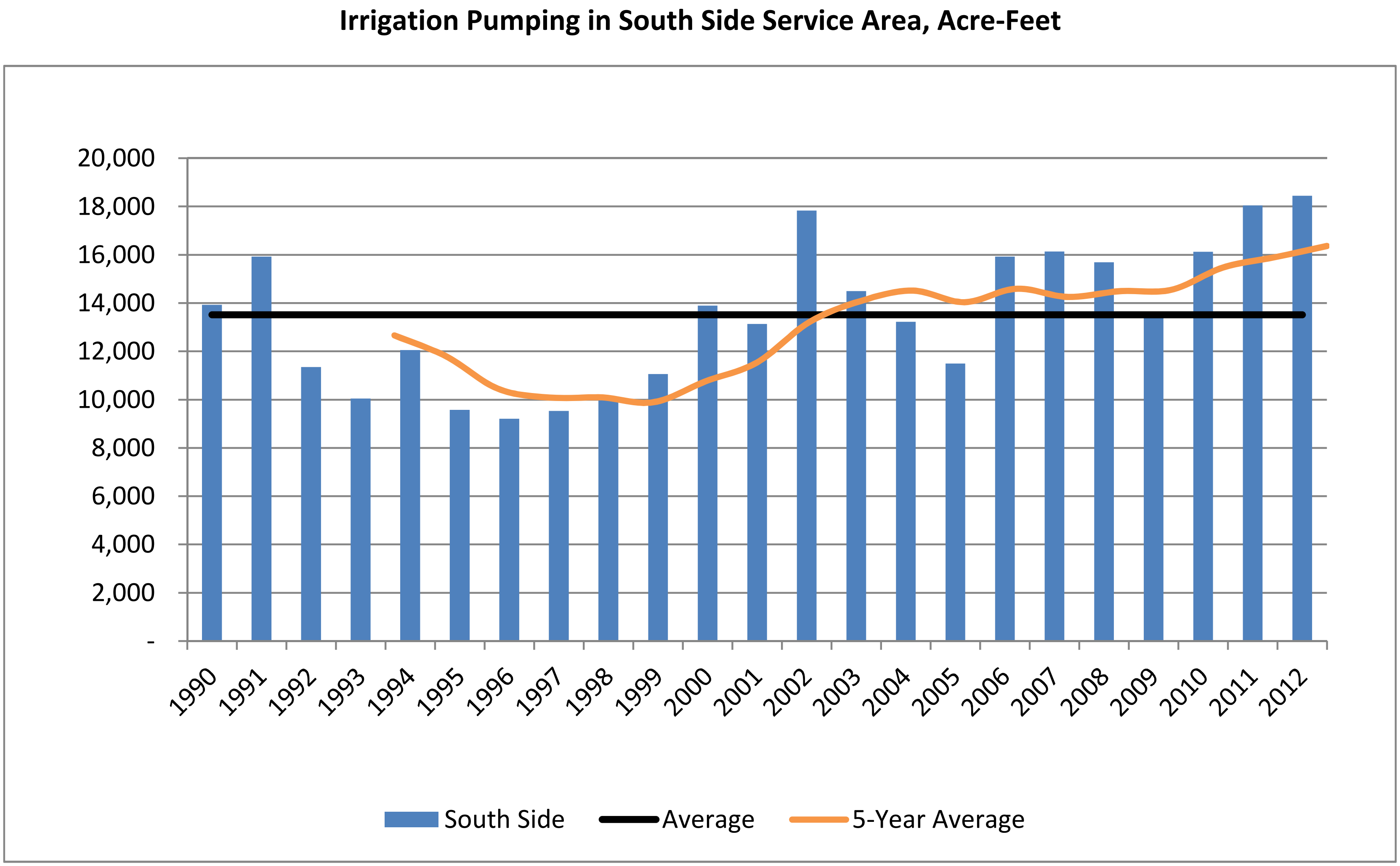
GMD3 System Optimization Study
Figure 5e



GMD3 System Optimization Study
Figure 5f

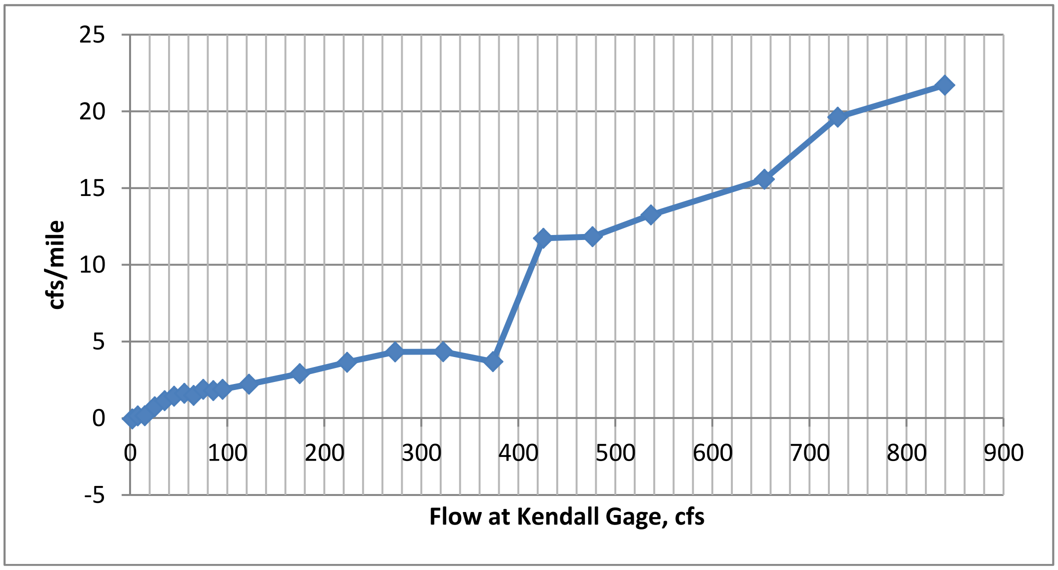


GMD3 System Optimization Study
Figure 5g

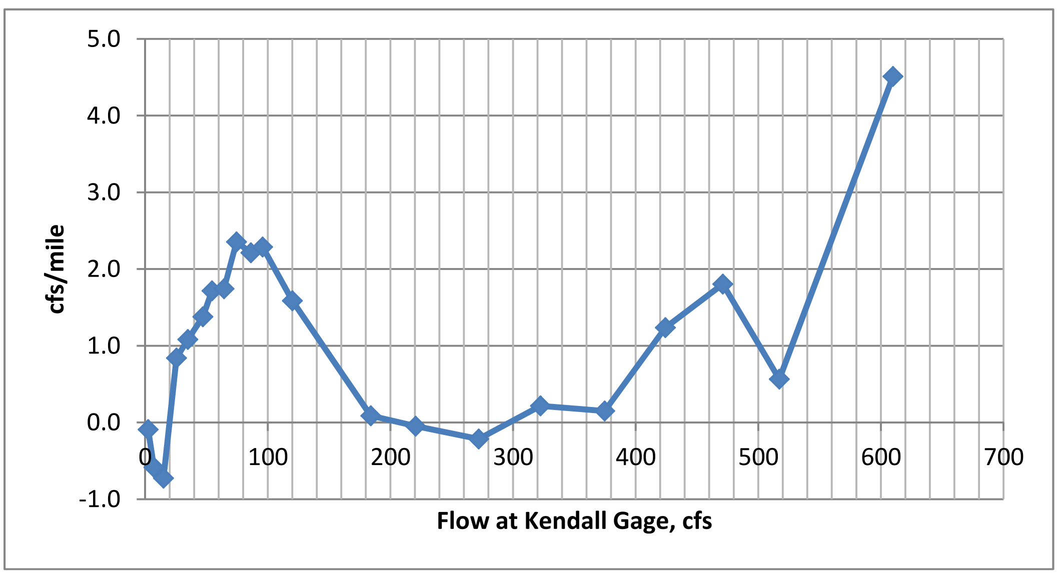


GMD3 System Optimization Study
Figure 6a

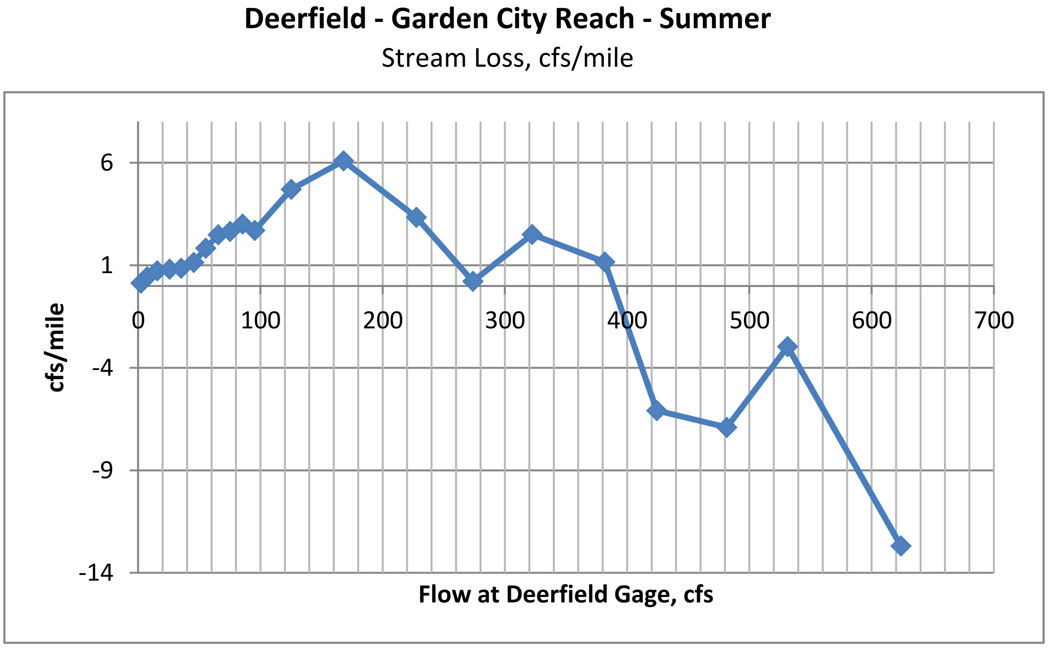
Kendall - Deerfield Reach - Summer
Stream Loss, cfs/mile

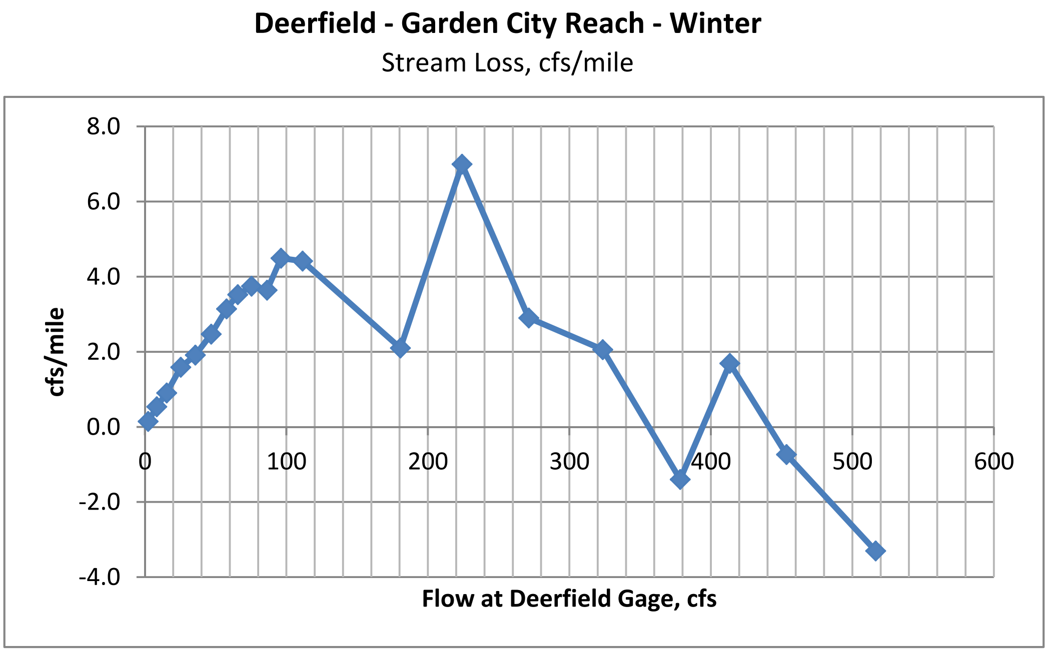


Kendall - Deerfield Reach - Winter
Stream Loss, cfs/mile

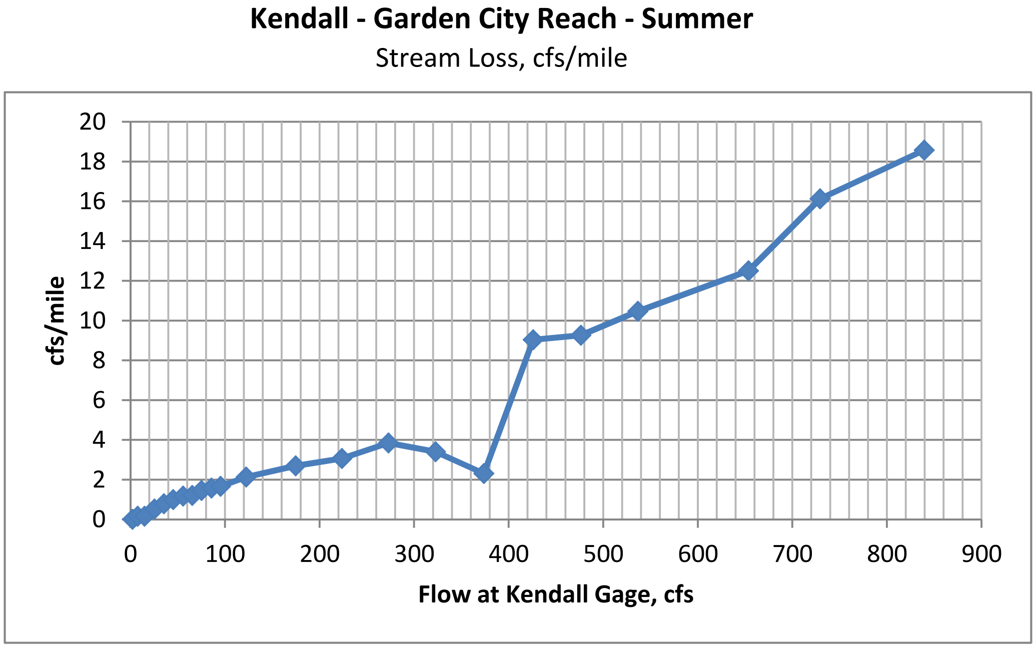


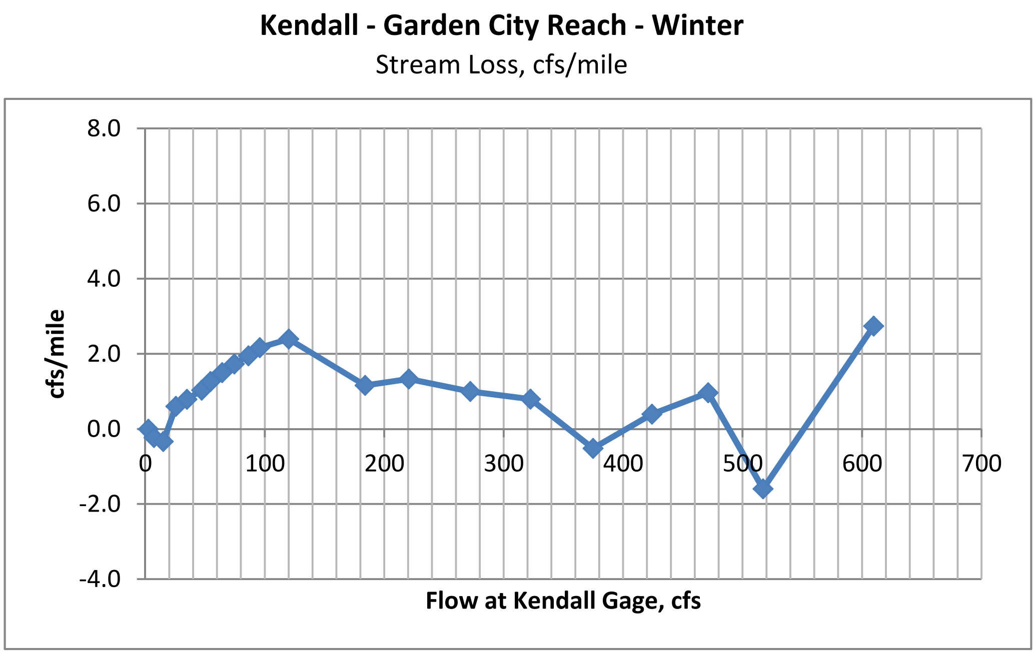
GMD3 System Optimization Study
Figure 6b





GMD3 System Optimization Study
Figure 6c





GMD3 System Optimization Study

Figure 7

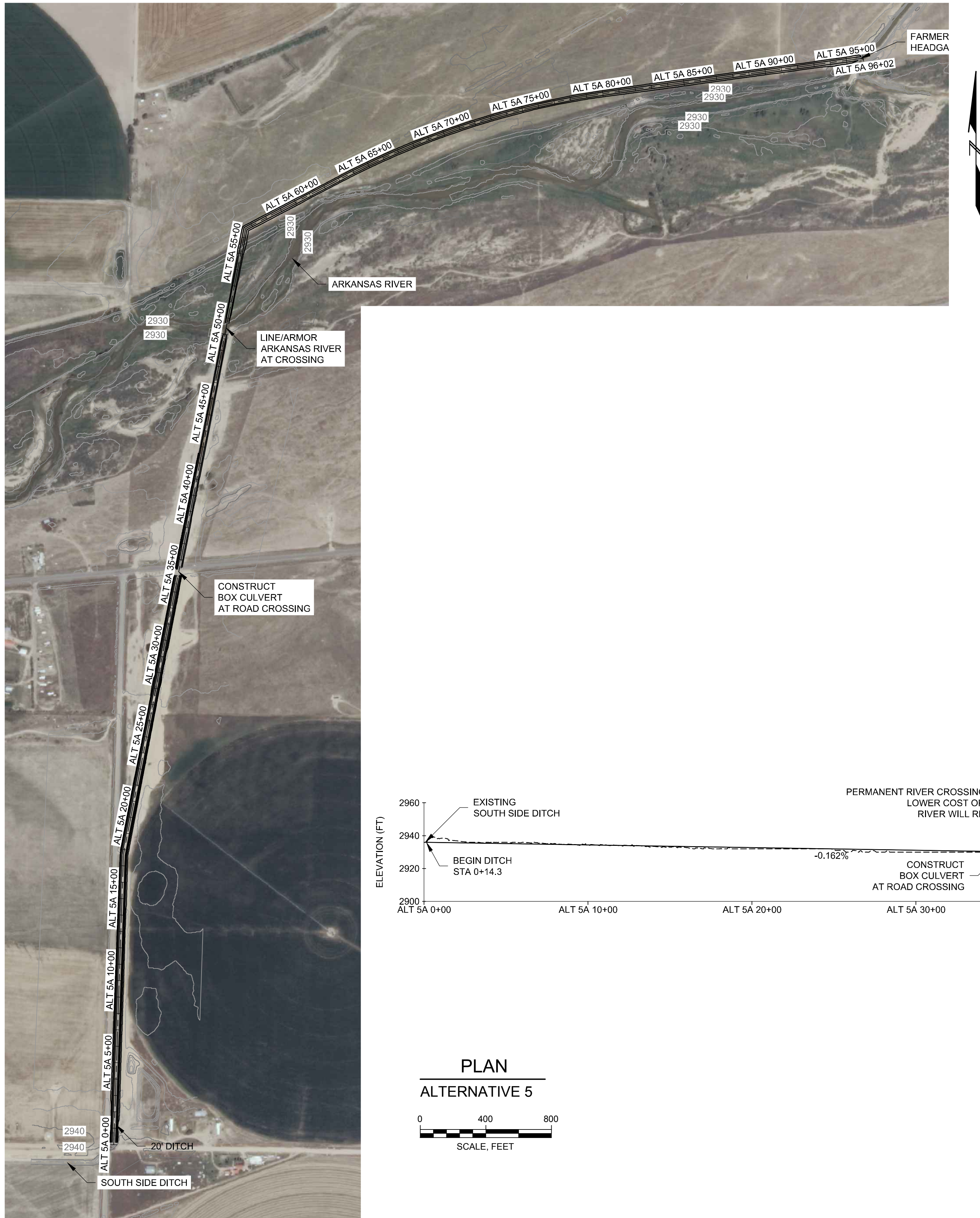
Farmers Ditch ADS Alternatives

Feet

2,000 1,000 0 2,000 4,000

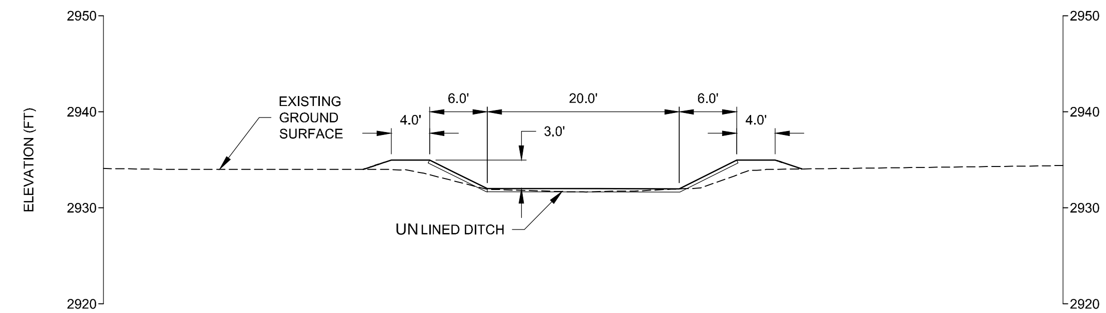
Approximate Scale = 1:35,000

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203



PLAN

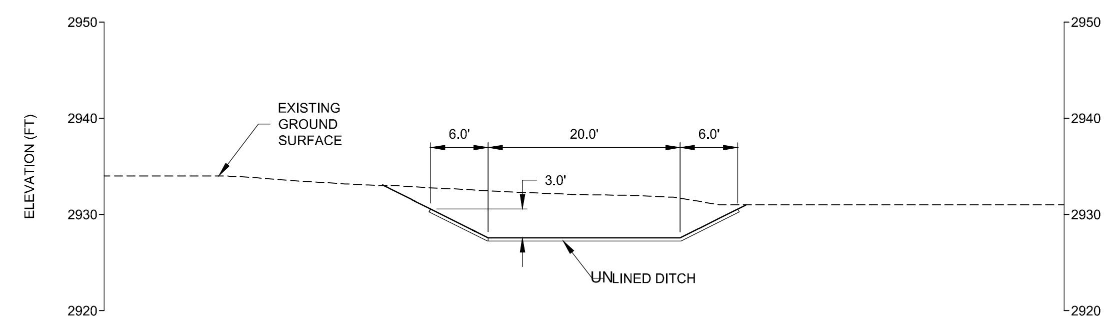
ALTERNATIVE 5



SECTION A

STA. 25+00

NOT TO SCALE



SECTION B

STA. 55+00

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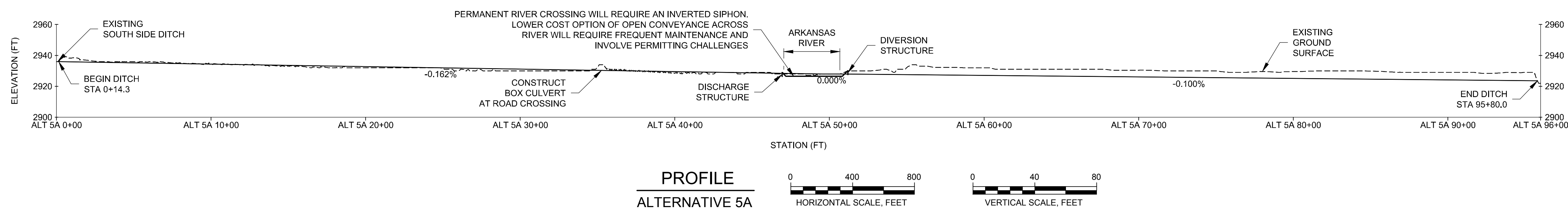


PROFILE

ALTERNATIVE 5A

System Optimization Review of the
Association Ditch System
Kearny and Finney Counties, Kansas

Southwest Kansas Groundwater Management District 3
Garden City, Kansas

GEI Consultants

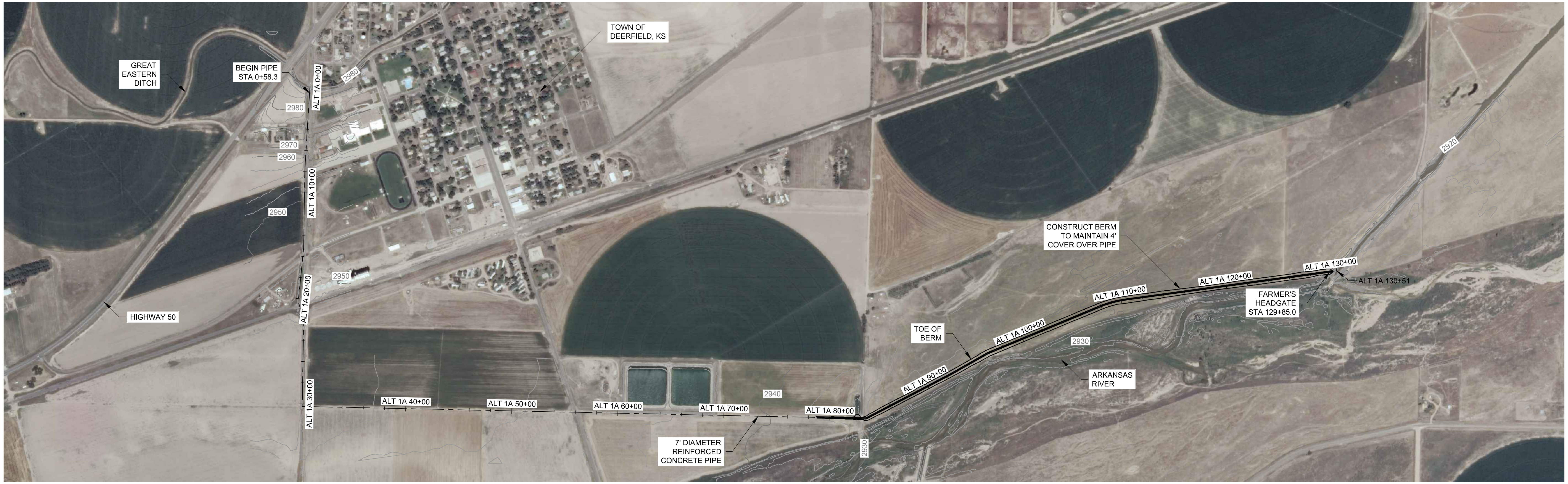
Project 116870

ALTERNATIVE 5
SOUTH SIDE DITCH RETURN
TO FARMER'S HEADGATE

September 2014

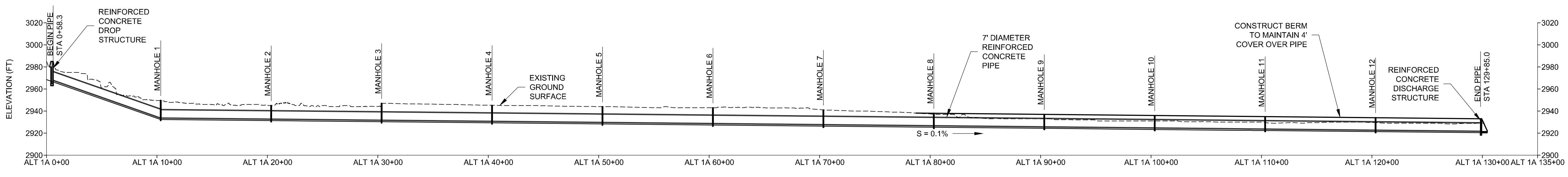
Figure 8a

P:\116870 - Spronk Water - GMD3\Civil\Production Drawings\Working Drawings\ Alternative 5A SSR to Farmers.dwg Sep 2014



PLAN
ALTERNATIVE 1A

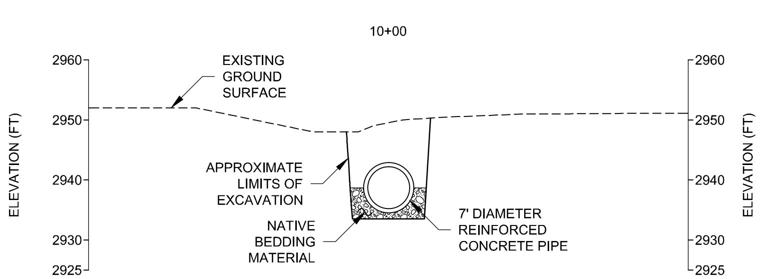
0 500 1000
SCALE, FEET



PROFILE
ALTERNATIVE 1A

0 500 1000
HORIZONTAL SCALE, FEET

0 50 100
VERTICAL SCALE, FEET



SECTION (A / -)
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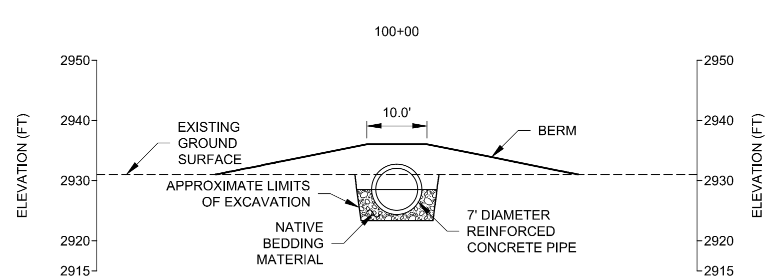

SECTION (B / -)
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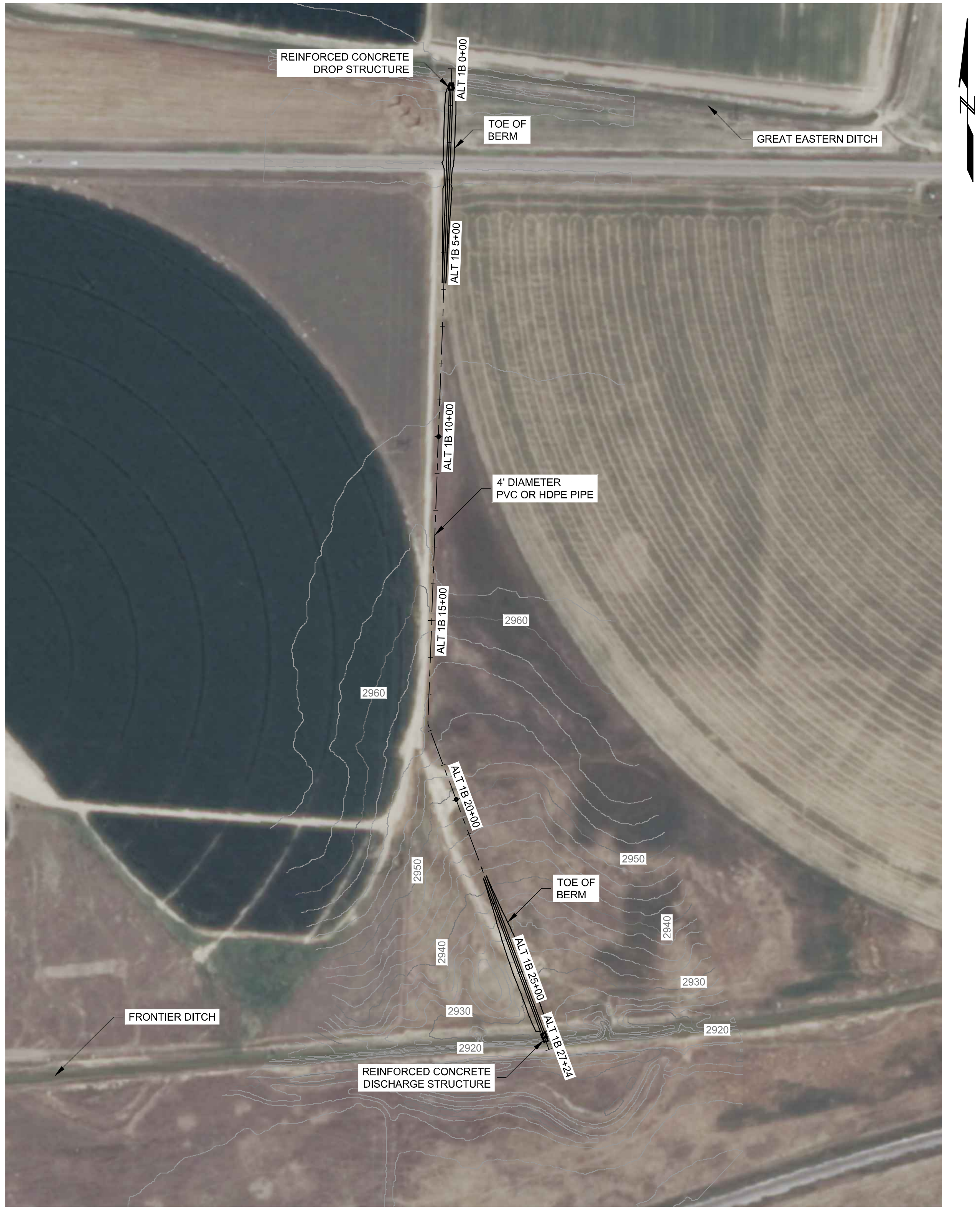
System Optimization Review of the Association Ditch System Kearny and Finney Counties, Kansas	GEI Consultants	ALTERNATIVE 1A GREAT EASTERN DITCH BYPASS TO FARMER'S HEADGATE
Southwest Kansas Groundwater Management District 3 Garden City, Kansas	Project 116870	September 2014 Figure 8b

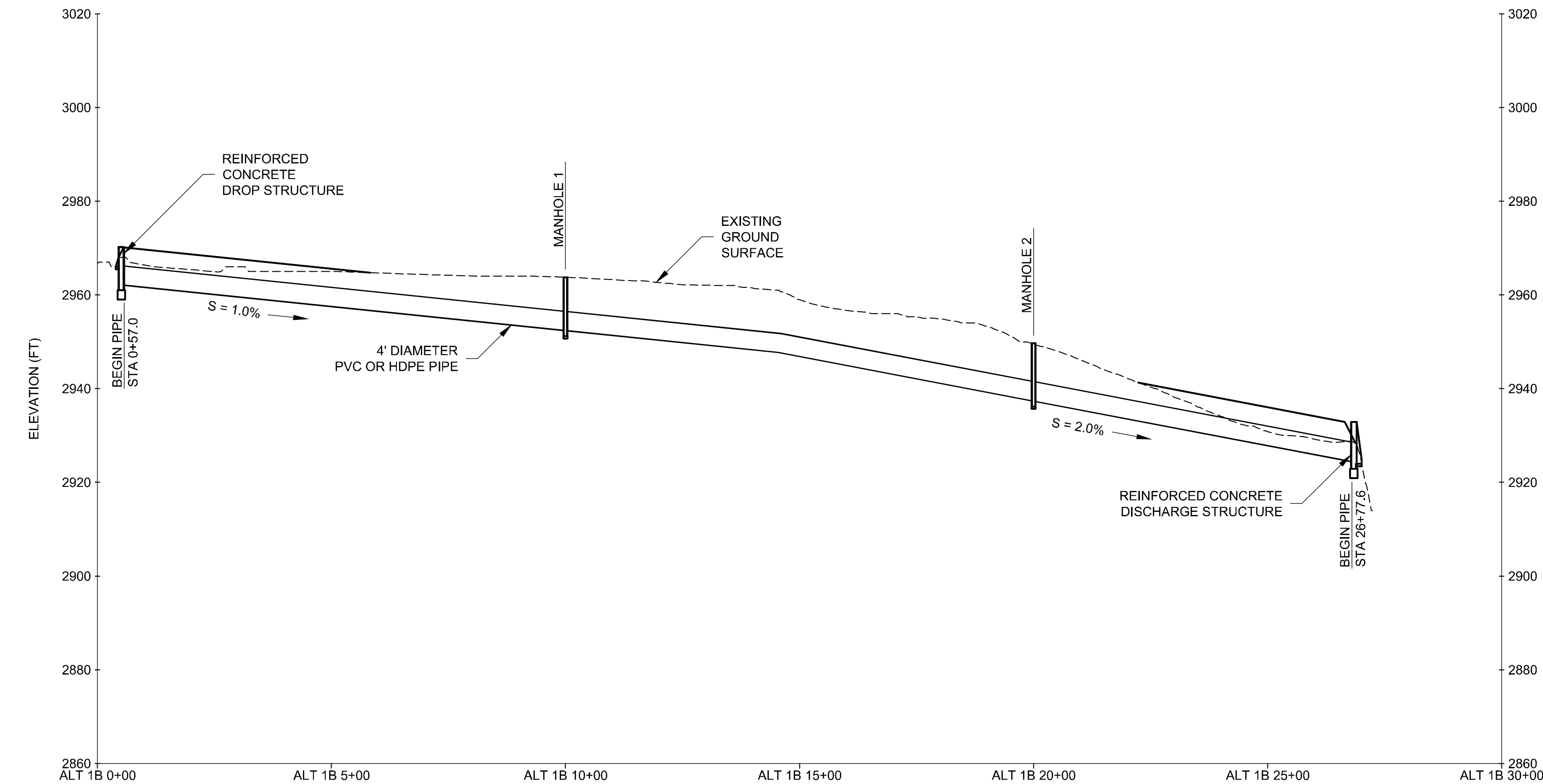
P:\116870 - Spronk Water - GMD3\Civil\Production Drawings\Working Drawings\ Alternative 1A GED Bypass to Farmers.dwg Jun 2014



PLAN

ALTERNATIVE 1B

0 200 400
SCALE, FEET

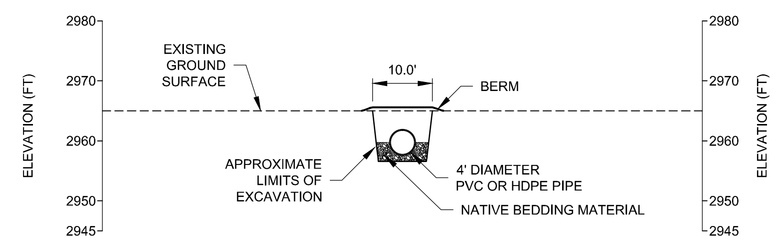


PROFILE

ALTERNATIVE 1B

0 200 400
HORIZONTAL SCALE, FEET

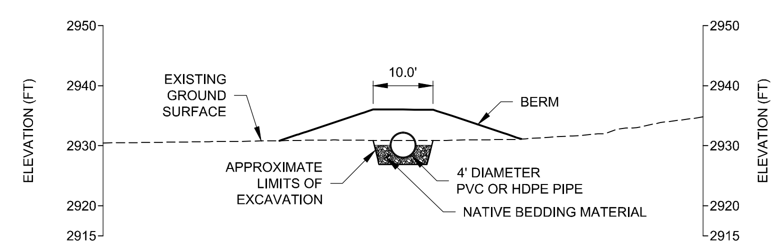
0 20 40
VERTICAL SCALE, FEET



SECTION A / -

STA. 5+00

NOT TO SCALE



SECTION B / -

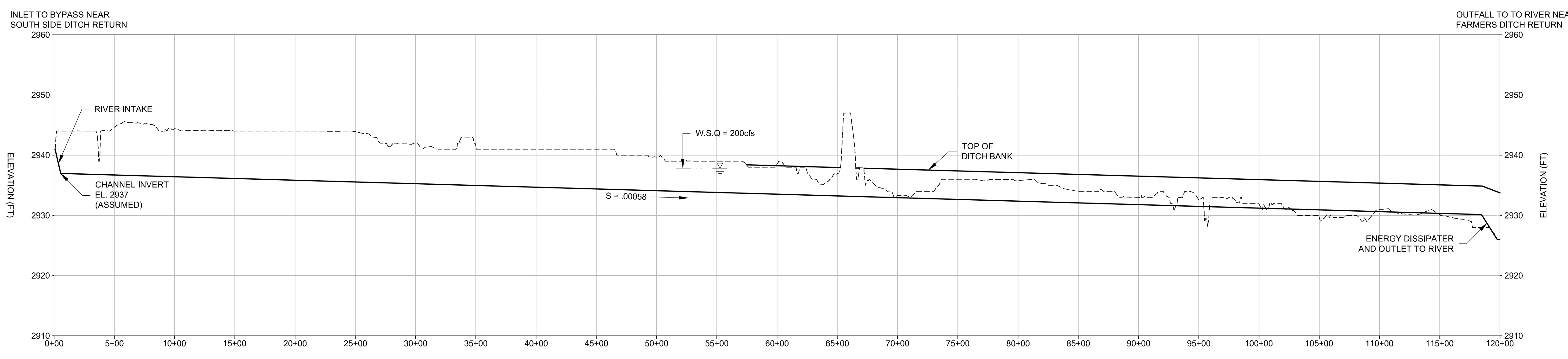
STA. 10+00

NOT TO SCALE

System Optimization Review of the Association Ditch System Kearny and Finney Counties, Kansas	GEI Consultants	ALTERNATIVE 1B GREAT EASTERN DITCH BYPASS TO FARMERS DITCH
Southwest Kansas Groundwater Management District 3 Garden City, Kansas	Project 116870	September 2014 Figure 8c

P:\116870 - Spronk Water - GMD3\Civil\Production Drawings\Working Drawings\ Alternative 1B GED to Frontier.dwg Jun 2014

0 500 1000
SCALE, FEET



0 500 1000
HORIZONTAL SCALE, FEET

0 10 20
VERTICAL SCALE, FEET

NOTES:

1. CHANNEL HAS 20' BOTTOM WIDTH, 2(H):1(V) SIDE SLOPES AND IS ASSUMED TO BE CONCRETE LINED.

System Optimization Review of the
Association Ditch System
Kearny and Finney Counties, Kansas

Southwest Kansas Groundwater Management District 3
Garden City, Kansas

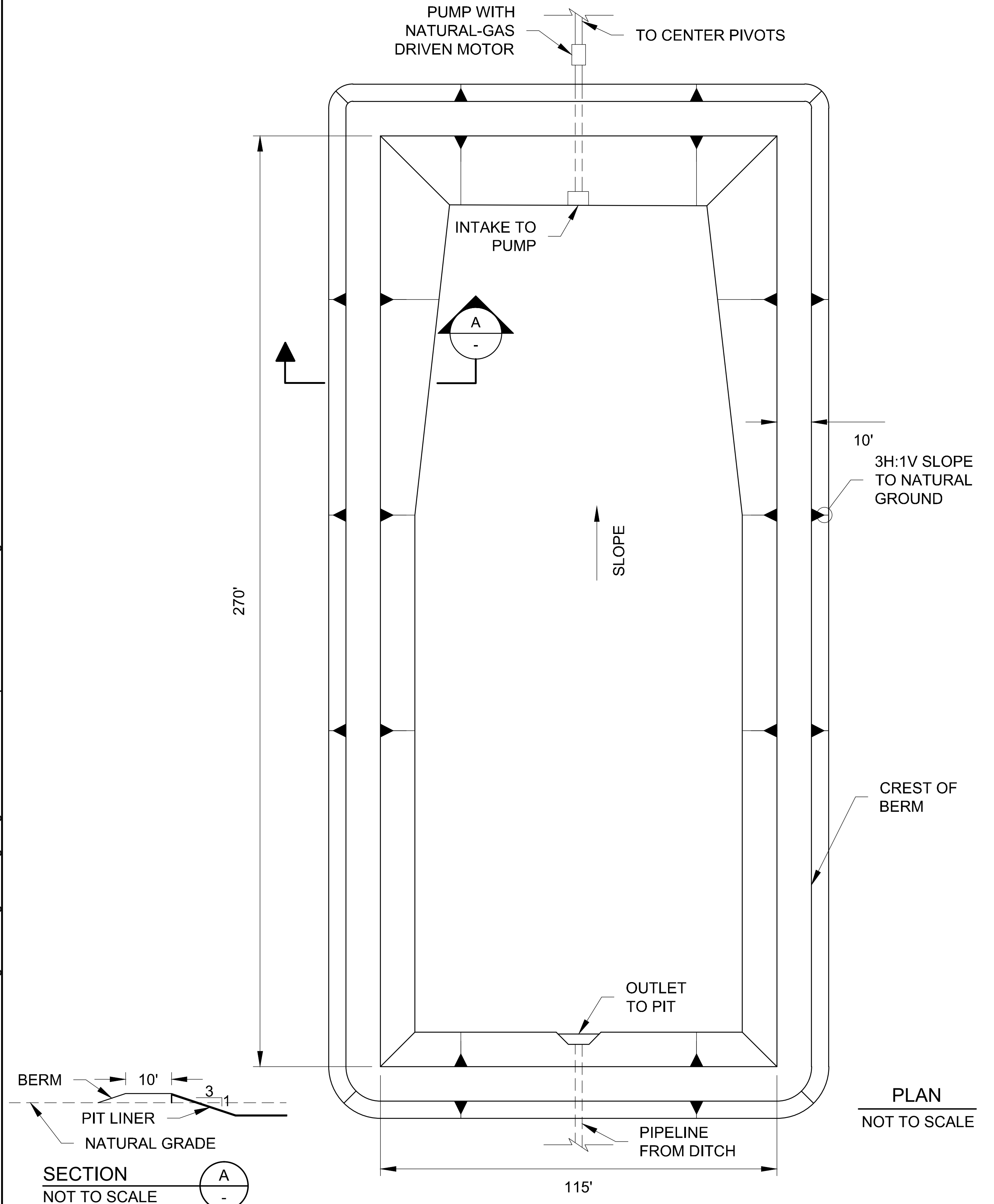
GEI Consultants

Project 116870

ARKANSAS RIVER
BYPASS CHANNEL
ALIGNMENT
PLAN AND PROFILE

September 2014 Figure 8d

P:\116870 - Spronk Water - GMD3\Civil\Production Drawings\Working Drawings\ Figure 4 - Arkansas River Plan and Profile 2.dwg Sep 2014



System Optimization Review of the
Association Ditch System
Kearny and Finney Counties, Kansas

Southwest Kansas Groundwater Management District 3
Garden City, Kansas

GEI Consultants

Project 116870

CENTER PIVOT
SPRINKLER SERVICE PIT

September 2014

Figure 8e

PLAN

NOT TO SCALE

DROP STRUCTURE

(NOVEMEBER 2013 PHOTO)

P:\116870 - Spronk Water - GMD3\Civil\Production Drawings\Working Drawings\ Figure 6 - Potential Hydroelectric Site.dwg Jun 2014

System Optimization Review of the
Association Ditch System
Kearny and Finney Counties, Kansas

Southwest Kansas Groundwater Management District 3
Garden City, Kansas

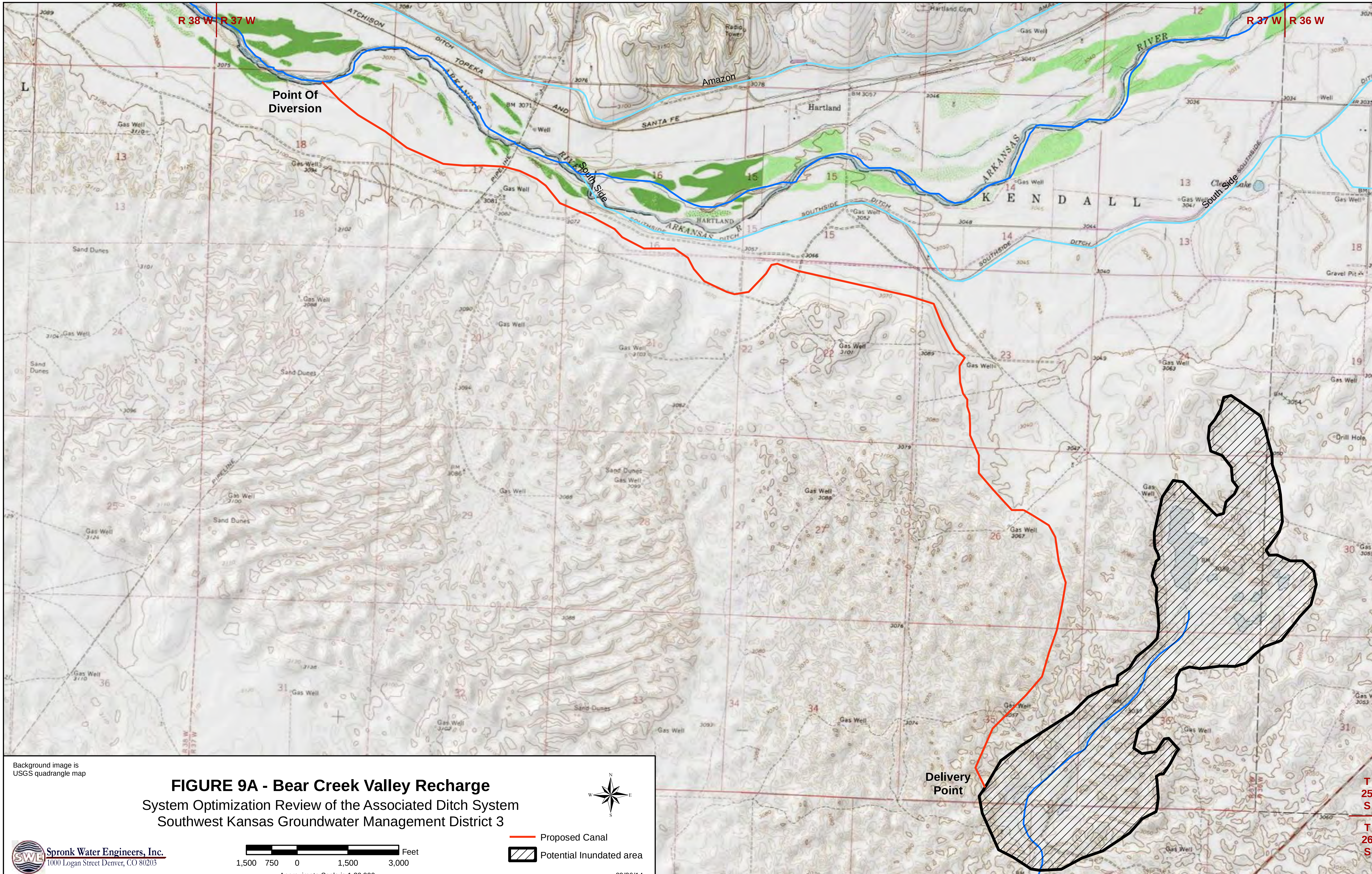
GEI Consultants

POTENTIAL HYDROELECTRIC DEVELOPMENT ON FRONTIER DITCH WASTEWAY

Project 116870

September 2014

Figure 8f



Background image is USGS quadrangle map

FIGURE 9A - Bear Creek Valley Recharge

System Optimization Review of the Associated Ditch System

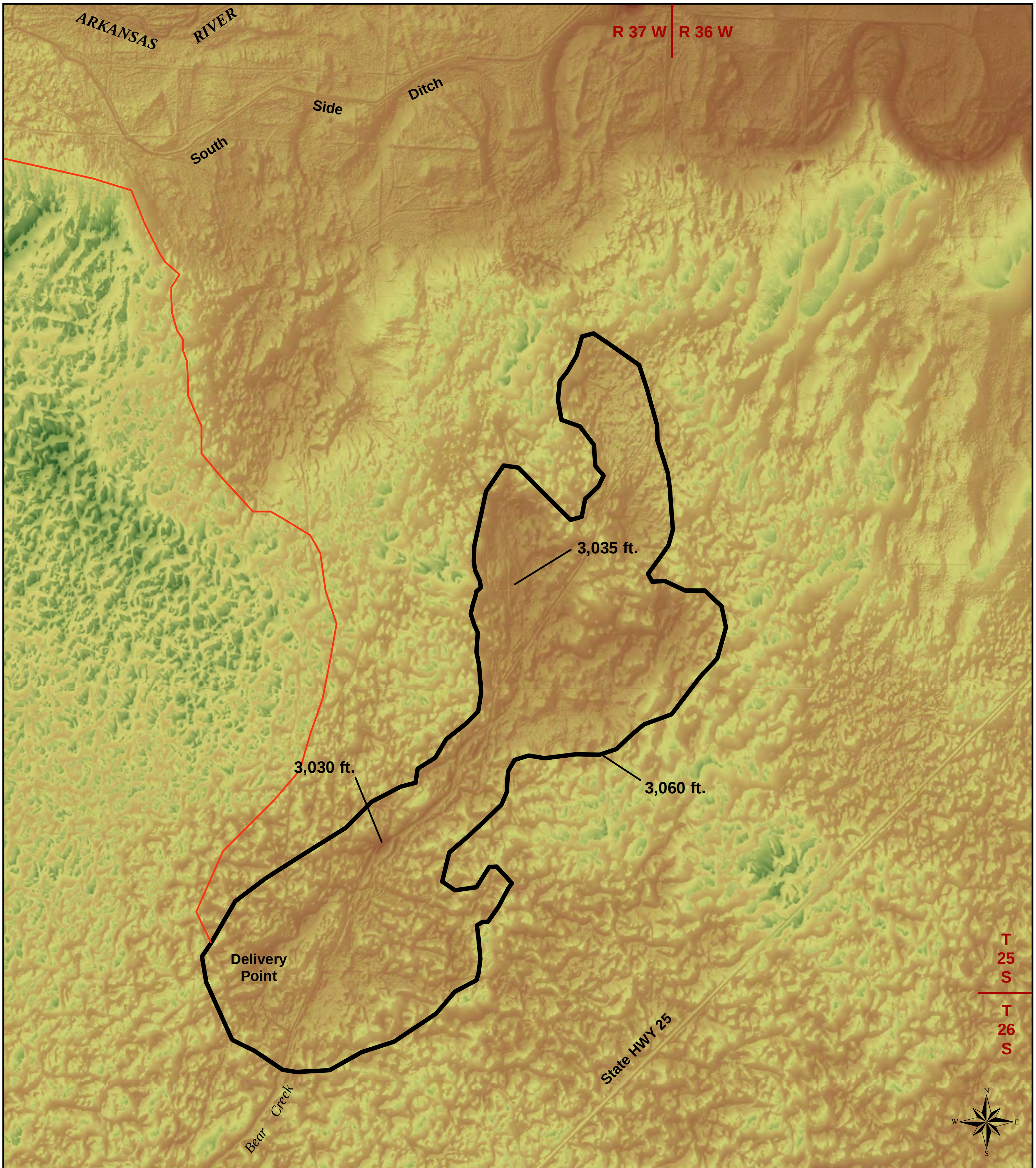
Southwest Kansas Groundwater Management District 3

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

Feet
1,500 750 0 1,500 3,000
Approximate Scale is 1:30,000

Proposed Canal
Potential Inundated area

09/26/14



Source: 2012 Lidar Data from GMD 3

FIGURE 9B - Bear Creek Valley Recharge Site Topography

Hillshaded Digital Elevation Model based on 2012 Lidar Data
Southwest Kansas Groundwater Management District 3

Elevation, ft abv sea level
High : 3,175
Low : 3,000

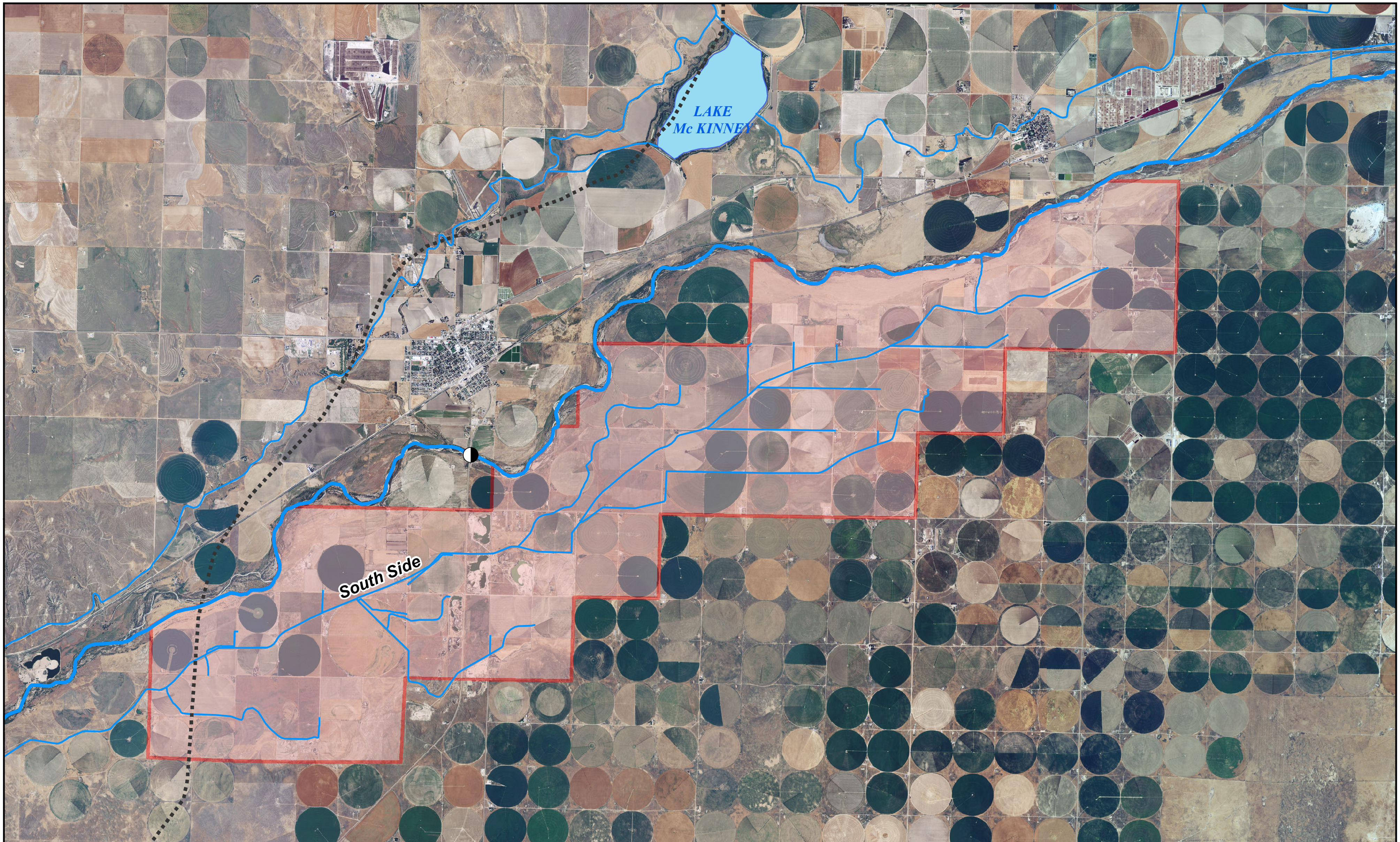
Proposed Canal
Potential Inundated area

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

1,500 750 0 1,500 3,000 Feet

Approximate Scale is 1:30,000

09/26/14



GMD3 System Optimization Study

Figure 10
South Side Service Area

South Side Service Area

Miles
1 0.5 0 1 2
Approximate Scale = 1:100,000

Spronk Water Engineers, Inc.
1000 Logan Street Denver, CO 80203

09/30/2014

APPENDICES

Appendix A

1982-2011 Monthly Streamflow Summary

Arkansas River at Coolidge, KS - USGS Gage # 07137500

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	1,035	2,081	3,305	3,257	3,156	1,214	2,109	12,339	13,533	12,014	10,661	6,944	71,649
1983	5,094	5,980	6,653	6,073	6,857	5,831	15,797	6,708	27,015	37,448	19,853	15,087	158,396
1984	7,450	8,569	9,340	8,007	8,517	10,423	6,857	23,836	33,412	24,189	29,705	20,382	190,688
1985	12,022	10,989	9,910	8,293	9,592	22,003	25,581	59,471	30,068	21,749	12,968	13,986	236,632
1986	11,441	10,622	10,027	8,658	15,551	30,248	19,178	20,373	29,574	35,961	17,762	15,598	224,992
1987	14,823	11,947	10,925	10,221	16,475	72,658	129,503	146,303	41,346	27,271	16,160	17,590	515,220
1988	15,239	13,349	11,697	11,885	11,984	24,950	15,545	22,392	36,161	36,784	15,793	12,278	228,057
1989	10,955	12,238	10,388	8,906	9,951	4,985	19,069	7,761	15,116	21,081	5,845	8,714	135,009
1990	6,663	7,833	8,926	7,216	8,374	5,915	4,786	10,042	11,358	3,826	1,587	4,209	80,734
1991	6,401	7,200	8,208	7,127	6,054	4,128	3,096	8,210	15,791	5,802	1,922	1,747	75,684
1992	5,494	6,617	6,490	5,831	5,453	3,654	2,085	5,058	21,057	10,158	3,253	3,451	78,600
1993	4,772	6,734	7,254	8,297	10,376	8,309	7,658	12,409	27,293	7,847	6,038	8,097	115,083
1994	8,864	9,602	9,406	7,839	5,877	7,531	5,554	15,535	26,775	10,959	4,905	7,051	119,899
1995	7,646	10,247	10,856	8,880	8,255	7,160	13,524	18,121	138,672	26,704	22,475	13,771	286,312
1996	11,568	11,754	12,040	10,152	12,147	26,853	42,612	29,610	39,882	31,327	23,056	14,973	265,973
1997	13,823	13,930	12,966	11,302	17,738	24,280	15,533	17,068	45,801	62,076	20,422	20,430	275,369
1998	25,226	32,857	59,755	31,669	40,438	55,308	22,578	38,414	45,444	31,254	14,245	18,514	415,702
1999	18,859	13,849	13,867	11,792	12,821	16,281	152,363	136,921	43,337	68,808	20,410	18,036	527,343
2000	17,504	15,612	15,196	22,919	26,686	18,595	18,330	40,547	41,878	32,359	9,360	17,389	276,375
2001	13,325	11,990	10,697	10,578	10,899	9,330	16,895	22,596	37,413	22,709	7,724	6,619	180,776
2002	5,960	7,325	7,869	6,603	5,784	5,254	3,541	6,137	7,107	4,376	3,719	2,926	66,600
2003	3,459	3,570	3,608	3,279	3,265	2,071	1,916	5,992	798	418	542	1,030	29,948
2004	1,154	2,265	2,469	2,426	3,072	16,263	3,771	9,271	6,413	6,087	2,878	3,995	60,064
2005	4,122	4,336	4,328	3,846	3,856	4,120	14,083	20,394	24,639	1,559	779	3,126	89,187
2006	3,989	3,771	4,110	3,193	2,902	1,267	877	2,395	18,911	3,691	5,106	7,220	57,431
2007	8,069	5,720	4,421	6,258	12,669	9,670	11,147	11,812	36,415	8,593	5,558	5,088	125,419
2008	6,040	7,220	6,881	6,149	6,068	5,213	3,751	5,556	30,135	8,977	6,181	6,617	98,786
2009	7,147	6,792	6,401	5,508	5,355	5,351	4,762	7,847	29,828	8,749	4,971	8,525	101,236
2010	8,922	8,069	7,670	6,706	7,633	6,095	4,665	14,648	29,052	8,573	3,927	3,447	109,408
2011	3,866	4,917	5,588	5,425	4,388	3,009	2,158	4,120	20,156	4,144	2,606	3,164	63,539
Mean	9,031	9,266	10,042	8,610	10,073	13,932	19,644	24,730	30,813	19,516	10,014	9,667	175,337

Source: Tabulation provided by USGS

Colorado - Kansas Stateline Flows

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	1,533	2,083	3,305	3,257	3,156	2,035	4,032	13,724	15,555	13,867	12,427	7,267	82,240
1983	5,094	6,367	6,653	6,073	6,857	5,863	18,054	7,969	28,872	39,801	20,257	15,087	166,947
1984	7,450	8,569	9,340	8,007	8,576	10,423	7,400	25,372	34,916	25,756	30,897	20,589	197,296
1985	12,022	10,989	9,910	8,293	9,592	22,995	26,494	60,800	32,162	23,164	14,185	14,756	245,361
1986	11,623	10,622	10,027	8,658	15,551	31,631	21,051	20,896	31,566	36,553	17,838	16,088	232,102
1987	14,823	11,947	10,925	10,221	16,475	72,836	131,711	147,725	42,853	29,395	17,136	18,934	524,981
1988	16,043	13,349	11,697	11,885	11,984	25,467	17,310	23,281	38,648	38,505	16,921	12,835	237,925
1989	11,652	12,238	10,388	8,906	9,951	7,339	19,636	8,905	17,342	22,133	6,839	9,890	145,218
1990	7,385	8,183	8,926	7,216	8,374	5,915	5,619	11,650	13,639	5,605	3,092	4,995	90,598
1991	6,857	7,200	8,208	7,127	6,054	5,391	3,989	9,615	17,642	5,917	3,003	2,707	83,709
1992	5,494	6,617	6,490	5,831	5,453	4,255	3,796	5,846	21,783	11,164	4,693	3,536	84,958
1993	4,967	6,769	7,261	8,297	10,376	8,309	7,658	13,156	28,575	9,494	6,866	8,434	120,162
1994	8,864	9,602	9,406	7,839	5,877	7,531	6,895	16,447	27,880	12,980	6,760	8,033	128,114
1995	9,076	10,912	10,856	8,880	8,255	7,160	13,748	18,745	139,932	29,155	24,464	14,977	296,160
1996	13,495	12,599	12,040	10,152	12,147	28,961	43,715	30,279	41,039	31,794	23,056	15,350	274,626
1997	13,823	13,930	12,966	11,302	17,738	24,492	16,715	17,935	47,419	62,902	21,973	20,767	281,964
1998	25,226	32,857	59,755	31,669	40,438	55,308	23,968	39,816	46,779	32,861	16,261	19,128	424,065
1999	18,886	14,545	13,867	11,792	12,821	16,281	152,622	139,121	45,880	70,766	21,982	18,037	536,598
2000	17,504	15,766	15,196	22,919	26,686	18,936	20,129	42,430	43,617	34,305	10,993	18,879	287,360
2001	13,325	11,990	10,697	10,578	10,899	9,330	17,385	23,947	39,160	24,641	9,104	8,126	189,184
2002	7,325	7,934	7,869	6,603	5,784	5,939	5,102	7,266	8,813	5,476	4,800	2,926	75,835
2003	3,459	3,570	3,608	3,279	3,265	2,712	3,152	6,442	1,903	1,201	1,421	1,895	35,906
2004	1,799	2,265	2,469	2,426	3,330	17,544	4,881	9,980	7,921	7,855	3,799	3,995	68,266
2005	4,122	4,336	4,328	3,846	3,856	4,252	15,586	20,807	26,271	3,180	1,800	3,420	95,803
2006	3,989	3,771	4,110	3,193	2,902	2,464	1,940	3,710	20,851	5,435	5,635	7,220	65,219
2007	8,069	5,720	4,421	6,258	12,669	9,670	12,127	13,141	38,407	10,431	6,725	6,077	133,715
2008	6,502	7,220	6,881	6,149	6,068	5,814	5,256	7,198	32,285	9,511	6,957	7,245	107,086
2009	7,147	6,792	6,401	5,508	5,355	5,702	6,321	9,783	31,911	10,255	5,675	8,525	109,374
2010	8,922	8,069	7,670	6,706	7,633	6,942	6,579	16,628	30,953	9,799	3,927	3,447	117,275
2011	3,866	4,917	5,588	5,425	4,388	3,762	3,379	5,142	21,797	5,582	3,658	3,383	70,884
Mean	9,345	9,391	10,042	8,610	10,084	14,509	20,875	25,925	32,546	20,983	11,105	10,218	183,631

Note:

Flow is the combined of the Ark River at Coolidge Gage, USGS Gage # 07137500, and the Frontier Ditch Diversions, USGS Gage # 07137000

Arkansas River at Syracuse, KS - USGS Gage # 07138000

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	1,686	2,015	3,035	2,906	3,100	1,581	2,271	10,161	13,414	9,902	10,318	7,067	67,457
1983	4,959	5,312	6,756	6,105	6,423	5,609	16,858	6,978	23,019	31,024	19,601	14,097	146,739
1984	6,548	7,934	6,712	7,857	7,997	10,435	7,698	22,586	33,476	21,055	27,466	20,860	180,623
1985	12,155	11,108	8,595	9,090	9,320	21,182	23,725	55,528	28,227	23,560	13,670	15,567	231,726
1986	12,119	10,909	10,858	9,404	15,321	33,374	19,774	20,747	31,214	32,603	21,233	16,102	233,658
1987	14,489	12,865	11,935	11,012	16,527	70,198	119,891	136,009	40,485	28,092	16,072	17,262	494,838
1988	14,985	13,980	12,333	12,256	12,036	24,345	15,457	20,488	36,812	37,972	17,931	12,327	230,923
1989	11,185	12,074	10,092	8,626	8,898	5,802	17,399	9,608	14,166	19,246	7,194	9,112	133,402
1990	5,945	7,496	8,533	7,480	8,571	5,822	5,677	8,983	10,735	3,957	1,557	3,305	78,059
1991	5,941	5,250	6,912	6,218	5,167	3,650	3,356	6,323	15,243	4,582	1,517	1,505	65,666
1992	4,808	6,062	6,187	5,750	5,040	3,396	1,853	3,624	19,934	11,379	3,229	3,070	74,332
1993	4,312	6,091	6,387	7,944	9,941	7,644	6,432	10,280	25,799	8,595	5,256	6,948	105,631
1994	8,283	9,362	9,856	8,662	5,956	6,827	5,215	12,839	24,927	11,824	5,451	6,811	116,013
1995	7,948	9,687	9,549	8,083	8,372	8,045	12,936	21,071	119,766	28,195	24,510	13,430	271,593
1996	12,585	12,446	11,849	10,441	11,475	24,040	40,565	30,865	38,908	33,103	24,685	17,584	268,546
1997	15,713	15,424	14,212	11,252	15,616	21,791	15,691	16,638	37,068	52,606	21,797	21,801	259,608
1998	25,089	33,049	60,729	33,505	39,394	53,771	24,147	36,223	42,447	32,277	13,990	17,752	412,374
1999	18,236	13,547	13,769	11,738	12,948	16,402	144,611	132,518	45,535	68,260	22,344	19,044	518,953
2000	18,577	16,281	14,938	22,086	24,560	16,810	18,696	37,566	38,992	28,203	8,985	16,681	262,375
2001	12,274	11,764	11,344	10,834	11,316	9,628	13,226	19,252	32,882	21,590	8,234	6,605	168,949
2002	6,058	7,432	7,377	6,914	6,323	5,802	4,066	4,280	6,506	2,159	2,785	1,863	61,565
2003	2,842	2,977	3,116	2,920	3,445	2,176	2,196	4,558	586	98	81	81	25,076
2004	261	1,285	1,890	1,928	2,208	14,656	4,165	8,458	6,700	5,492	2,301	3,550	52,896
2005	3,773	4,034	4,064	3,796	3,832	3,717	12,528	18,284	23,796	1,989	598	2,100	82,511
2006	3,431	3,443	3,771	2,949	2,811	1,517	667	1,206	14,920	3,757	5,342	5,782	49,596
2007	7,581	5,381	3,981	6,379	12,429	9,979	11,338	11,104	33,021	8,860	5,443	4,895	120,391
2008	5,814	6,823	6,391	5,518	5,324	4,580	3,414	3,493	23,598	8,507	5,623	5,701	84,785
2009	6,444	6,286	6,115	5,185	4,840	4,788	4,457	7,133	25,732	9,241	4,707	7,349	92,276
2010	8,158	7,670	7,434	6,476	7,884	6,698	4,776	11,449	29,007	8,293	3,374	2,646	103,866
2011	3,154	4,237	5,151	4,814	4,403	3,150	1,966	3,011	16,239	4,157	1,749	2,464	54,495
Mean	8,845	9,074	9,796	8,604	9,716	13,580	18,835	23,042	28,438	18,686	10,235	9,445	168,297

Source: USGS and Tabulation provided by KDWR

Arkansas River at Kendall, KS - USGS Gage # 07138020

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	1,392	1,545	2,400	2,567	3,017	1,007	1,394	7,886	14,323	9,164	9,763	-	54,458
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	-	35,233	39,182	28,644	10,154	16,955	130,167
2001	13,095	12,024	11,425	11,141	11,437	9,834	14,829	19,770	31,436	22,059	7,823	6,692	171,565
2002	6,266	7,892	8,107	7,069	6,710	5,770	4,265	3,953	6,823	1,412	2,985	1,648	62,901
2003	2,626	3,037	3,132	2,858	3,491	2,134	2,241	4,778	1,173	85	41	26	25,623
2004	56	1,059	1,571	1,868	1,926	12,427	4,253	6,068	6,020	4,475	1,960	3,548	45,230
2005	3,646	3,890	4,338	4,122	3,902	3,449	11,121	16,653	21,009	2,995	1,208	1,714	78,047
2006	3,265	3,465	3,753	3,267	3,037	1,813	739	539	12,563	3,314	4,409	4,661	44,826
2007	7,414	5,647	4,316	6,778	13,524	11,022	11,588	11,215	28,158	9,693	5,863	4,891	120,109
2008	5,467	6,750	6,996	6,105	5,974	5,012	3,564	2,951	20,220	8,727	5,822	5,574	83,162
2009	6,732	6,901	6,121	5,447	4,850	5,244	4,626	7,190	22,697	10,316	4,790	6,905	91,818
2010	8,646	7,831	7,950	7,026	8,035	7,222	5,189	9,067	26,537	7,700	3,219	-	98,421
2011	-	-	-	-	-	-	547	1,796	12,934	3,959	1,386	2,095	22,718
Mean	1,953	2,001	2,004	1,942	2,197	2,165	2,145	4,237	8,103	3,751	1,981	1,824	34,302

Source: Tabulation provided by KDWR

Arkansas River at Kendall, KS - Combined Data

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	1,392	1,545	2,400	2,567	3,017	1,007	1,394	7,886	14,323	9,164	9,763	6,814	61,272
1983	4,870	5,204	6,529	5,900	6,223	5,466	15,795	6,722	21,446	28,789	18,300	13,262	138,505
1984	6,327	7,609	6,489	7,517	7,668	9,893	7,393	21,038	31,038	19,645	25,514	19,466	169,596
1985	11,470	10,520	8,215	8,638	8,881	19,750	22,093	51,255	26,223	21,942	12,860	14,610	216,460
1986	11,438	10,338	10,291	8,925	14,385	30,934	18,469	19,352	28,963	30,237	19,798	15,102	218,232
1987	13,612	12,132	11,279	10,401	15,491	64,711	110,302	125,076	37,467	26,100	15,064	16,166	457,800
1988	14,067	13,155	11,645	11,552	11,372	22,652	14,510	19,114	34,098	35,162	16,768	11,639	215,734
1989	10,581	11,406	9,589	8,212	8,494	5,643	16,291	9,134	13,326	17,985	6,920	8,690	126,271
1990	5,774	7,207	8,159	7,161	8,193	5,661	5,539	8,561	10,178	3,962	1,749	3,363	75,507
1991	5,770	5,148	6,672	6,003	5,071	3,669	3,410	6,121	14,314	4,535	1,713	1,713	64,140
1992	4,731	5,892	6,007	5,585	4,955	3,436	2,031	3,645	18,617	10,770	3,283	3,148	72,099
1993	4,276	5,919	6,190	7,586	9,451	7,333	6,232	9,751	23,997	8,215	5,143	6,705	100,798
1994	7,919	8,919	9,372	8,245	5,795	6,583	5,115	12,098	23,196	11,177	5,321	6,580	110,321
1995	7,611	9,218	9,090	7,714	8,011	7,701	12,198	19,648	110,188	26,194	22,803	12,651	253,028
1996	11,865	11,748	11,201	9,888	10,857	22,372	37,540	28,632	36,021	30,695	22,963	16,461	250,244
1997	14,734	14,479	13,368	10,621	14,656	20,309	14,725	15,582	34,332	48,585	20,314	20,329	242,035
1998	23,334	30,646	56,036	31,033	36,467	49,643	22,481	33,547	39,267	29,939	13,153	16,615	382,160
1999	17,049	12,758	12,962	11,067	12,209	15,366	132,977	121,874	42,099	62,944	20,816	17,800	479,920
2000	17,361	15,265	12,845	18,312	25,282	18,621	18,707	35,233	39,182	28,644	10,154	16,955	256,561
2001	13,095	12,024	11,425	11,141	11,437	9,834	14,829	19,770	31,436	22,059	7,823	6,692	171,565
2002	6,266	7,892	8,107	7,069	6,710	5,770	4,265	3,953	6,823	1,412	2,985	1,648	62,901
2003	2,626	3,037	3,132	2,858	3,491	2,134	2,241	4,778	1,173	85	41	26	25,623
2004	56	1,059	1,571	1,868	1,926	12,427	4,253	6,068	6,020	4,475	1,960	3,548	45,230
2005	3,646	3,890	4,338	4,122	3,902	3,449	11,121	16,653	21,009	2,995	1,208	1,714	78,047
2006	3,265	3,465	3,753	3,267	3,037	1,813	739	539	12,563	3,314	4,409	4,661	44,826
2007	7,414	5,647	4,316	6,778	13,524	11,022	11,588	11,215	28,158	9,693	5,863	4,891	120,109
2008	5,467	6,750	6,996	6,105	5,974	5,012	3,564	2,951	20,220	8,727	5,822	5,574	83,162
2009	6,732	6,901	6,121	5,447	4,850	5,244	4,626	7,190	22,697	10,316	4,790	6,905	91,818
2010	8,646	7,831	7,950	7,026	8,035	7,222	5,189	9,067	26,537	7,700	3,219	2,759	101,180
2011	3,214	4,218	5,057	4,715	4,371	3,210	2,023	1,796	12,934	3,959	1,386	2,095	48,979
Mean	8,487	8,728	9,370	8,244	9,458	12,930	17,721	21,275	26,262	17,647	9,730	8,953	158,804

Source:

Tabulation provided by KDWR for periods of 03/1980-09/1982, 06/2000-09/2010, and 05/2011-10/2011

Data for missing periods was estimated using the data from the Arkansas River at Syracuse Gage

Arkansas River at Deerfield, KS - USGS Gage # 07138070

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982													
1983													
1984													
1985													
1986													
1987													
1988													
1989													
1990													
1991													
1992													
1993													
1994													
1995													
1996													
1997													
1998													
1999	18,835	13,399	11,453	12,498	12,879	15,642	128,069	127,777	32,871	54,334	19,315	19,030	466,101
2000	17,473	17,014	12,663	17,955	23,762	14,924	12,450	9,217	13,851	8,825	4,183	6,585	158,902
2001	11,699	10,983	11,780	8,815	8,813	8,019	11,657	15,937	9,174	8,575	4,584	2,731	112,766
2002	4,209	5,695	4,733	4,614	3,709	879	1,901	58	764	-	-	-	26,561
2003	341	942	568	2	380	33	224	111	-	-	-	-	2,601
2004	-	-	-	-	-	87	467	726	1,400	207	-	122	3,010
2005	1,104	1,864	1,472	7	-	458	5,419	2,201	2,272	-	-	-	14,797
2006	113	449	1,079	70	881	281	-	-	-	-	-	-	2,872
2007	-	179	906	6,002	10,130	7,246	6,855	2,985	4,822	637	1,962	1,619	43,342
2008	2,886	3,654	3,414	2,648	29	212	1,260	-	719	1,853	1,292	2,212	20,178
2009	4,005	3,717	4,239	1,178	4	2,063	1,576	2,017	2,237	2,165	1,161	2,667	27,029
2010	5,939	5,111	5,203	5,484	6,062	841	-	927	3,781	4,213	-		37,562
2011													
Mean	5,550	5,251	4,792	4,939	5,554	4,224	14,156	13,496	5,991	6,734	2,708	3,179	76,310

Source: Tabulation provided by KDWR

Arkansas River at Garden City, KS - USGS Gage # 07139000

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	8	4	4	20	20	4	16	4	79
1983	-	-		8	24	296	24	36	-	-	4	-	391
1984	-	-	-	2,603	321	2,025	751	4	12	-	-	1,349	7,063
1985	4,533	868		4,262	3,270	954	4,072	20,656	311	1,006	54		39,988
1986	10,011	3,973										8,051	22,035
1987	11,320	8,961	6,185	5,034	5,607	46,386	87,651	103,983	30,147	1,078	4,413	5,003	315,769
1988	6,706	10,993	8,995	11,020	6,795	2,856	255	6,078	-	-	5,867	172	59,737
1989	2,333	6,676	6,567	5,029	667	-	3,336	5,199	2,371	0	1,319	-	33,498
1990	83	134	5,252	3,757	854	440	290	56	13	-	-	-	10,878
1991	-	-	27	1,533	-	-	-	-	-	-	-	-	1,560
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	1,450	3,880	5,933	1,343	18	0	2	1	28	12,655
1994	2,080	5,012	3,767	4,735	2,248	6	3	0	0	0	1	-	17,854
1995	-	377	3,894	3,238	2,843	4	1,974	13,042	76,345	26,516	1,696	6,847	136,773
1996	8,025	9,455	10,003	8,339	6,752	6	10,762	25,661	5,397	21,398	27,265	15,088	148,151
1997	12,014	12,425	12,756	9,110	7,712	3,808	7,842	12,278	30	39,173	9,804	14,273	141,226
1998	22,070	24,683	51,849	34,200	29,467	45,527	14,474	4,240	9,556	23,877	3,851	13,305	277,099
1999	18,373	13,408	11,346	13,077	12,026	13,053	108,248	109,836	23,546	40,539	12,365	15,602	391,420
2000	13,516	14,664	12,028	18,008	25,706	15,374	8,099	1,452	7,873	2,417	13	1,871	121,022
2001	9,203	9,207	10,612	8,136	7,482	7,216	8,394	17,604	854	1,828	202	12	80,750
2002	1,803	3,993	3,610	2,868	3,060	-	-	-	-	-	-	-	15,334
2003	-	-	-	-	-	-	-	0	-	0	-	-	0
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	3	1	14	1	5	3	10	16	-	54
2008	-	-	-	-	-	-	-	14	3	24	2	22	65
2009	-	-	-	-	0	26	1	15	11	6	1	12	71
2010	1	-	-	112	771	54	36	-	-	-	-	-	975
2011	-	-	-	-	0	-	-	-	-	-	-	-	0
Mean	4,069	4,161	5,440	4,708	4,120	4,965	8,881	11,041	5,396	5,444	2,307	2,815	61,148

Source:

1980-1985 data from PL Exhibit 644 (Kansas v Colorado)

1986-2011 USGS

Arkansas River at Dodge City, KS - USGS Gage # 07139500

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	-	-	-	22	3	-	-	25
1983	-	-	-	-	-	-	-	10	-	-	28	-	38
1984	-	-	-	-	-	2	-	-	-	-	-	-	2
1985	-	0	-	-	-	-	-	0	0	1	-	-	1
1986	-	-	1,129	676	1,248	383	0	24	0	185	-	-	3,645
1987	-	225	1,502	3,043	3,471	29,477	59,315	102,069	41,374	4,973	1,394	1,193	248,035
1988	2,138	3,852	2,289	8,243	6,085	3,346	690	720	21	-	-	-	27,385
1989	-	-	-	-	-	-	-	-	109	-	-	-	109
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	25	-	-	-	25
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	14,684	16,921	-	-	31,605
1996	-	-	0	-	-	-	-	1,858	279	3,775	15,602	8,440	29,954
1997	5,673	3,273	4,711	3,779	3,283	2,057	381	4,610	270	22,207	7,627	6,212	64,080
1998	13,849	16,566	40,011	32,779	25,381	35,566	13,456	3,691	1,437	12,716	598	2,752	198,803
1999	9,116	6,252	6,183	7,293	7,609	9,176	81,538	106,500	29,624	29,274	8,795	10,112	311,471
2000	8,547	10,027	7,406	10,755	18,980	11,655	5,978	163	-	-	-	-	73,510
2001	-	-	-	518	1,300	1,565	28	7,903	0	-	-	-	11,314
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	843	107	-	950
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	1,311	1,340	2,108	2,236	2,245	3,108	5,380	7,585	2,928	3,030	1,138	957	33,365

Source: USGS

Appendix B

1982-2011 Monthly Ditch Diversion Summary

Frontier Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	821	1,923	1,385	2,021	1,853	1,765	323	10,091
1983	-	387	-	-	-	32	2,258	1,261	1,857	2,353	404	-	8,551
1984	-	-	-	-	59	-	543	1,536	1,504	1,567	1,192	207	6,609
1985	-	-	-	-	-	992	912	1,329	2,094	1,415	1,217	770	8,729
1986	182	-	-	-	-	1,382	1,872	523	1,992	592	76	490	7,110
1987	-	-	-	-	-	179	2,208	1,422	1,507	2,124	976	1,345	9,761
1988	804	-	-	-	-	516	1,765	889	2,486	1,721	1,128	557	9,868
1989	697	-	-	-	-	2,354	566	1,143	2,225	1,053	994	1,176	10,209
1990	723	350	-	-	-	-	833	1,607	2,281	1,779	1,505	786	9,864
1991	456	-	-	-	-	1,263	892	1,405	1,851	115	1,081	960	8,025
1992	0	-	-	-	-	601	1,712	788	726	1,006	1,440	84	6,358
1993	195	35	7	-	-	-	-	747	1,282	1,648	829	337	5,080
1994	-	-	-	-	-	-	1,341	912	1,105	2,021	1,855	981	8,215
1995	1,430	666	-	-	-	-	224	623	1,259	2,452	1,989	1,205	9,848
1996	1,927	845	-	-	-	2,108	1,104	670	1,157	466	-	376	8,653
1997	-	-	-	-	-	212	1,183	867	1,618	826	1,551	337	6,595
1998	-	-	-	-	-	-	1,390	1,402	1,335	1,607	2,015	614	8,363
1999	26	696	-	-	-	-	260	2,200	2,542	1,958	1,571	1	9,255
2000	-	154	-	-	-	341	1,799	1,884	1,739	1,946	1,632	1,490	10,985
2001	-	-	-	-	-	-	489	1,351	1,747	1,932	1,381	1,507	8,407
2002	1,365	609	-	-	-	684	1,561	1,129	1,706	1,101	1,081	-	9,235
2003	-	-	-	-	-	641	1,236	449	1,105	783	879	865	5,958
2004	645	-	-	-	258	1,282	1,111	709	1,509	1,767	921	-	8,201
2005	-	-	-	-	-	132	1,503	412	1,632	1,621	1,022	294	6,616
2006	-	-	-	-	-	1,196	1,063	1,252	1,543	1,743	530	-	7,327
2007	-	-	-	-	-	-	980	1,329	1,991	1,839	1,167	990	8,296
2008	462	-	-	-	-	602	1,505	1,642	2,150	534	777	628	8,299
2009	-	-	-	-	-	350	1,559	1,936	2,083	1,505	705	-	8,138
2010	-	-	-	-	-	847	1,914	1,980	1,900	1,226	-	-	7,867
2011	-	-	-	-	-	753	1,221	1,022	1,640	1,438	1,051	219	7,345
Mean	297	125	0	-	11	576	1,231	1,194	1,720	1,466	1,091	551	8,262

Source: USGS

Amazon Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	1,803	143	-	105	2,945	-	-	4,915	9,912
1983	-	-	-	-	-	-	3,717	1,621	4,237	5,139	2,817	3,029	20,559
1984	1,676	-	-	-	594	4,990	3,086	2,924	7,825	4,165	3,860	4,893	34,014
1985	-	-	-	-	-	3,193	5,617	9,096	8,358	6,198	1,938	-	34,402
1986	-	-	-	-	1,384	11,550	5,470	4,284	8,045	7,952	2,035	-	40,721
1987	-	-	-	-	-	1,849	5,635	5,439	9,872	8,446	1,658	4,941	37,839
1988	284	-	-	-	-	8,081	1,131	4,626	12,008	8,912	-	6,034	41,074
1989	-	-	-	-	879	3,041	-	734	6,873	4,395	1,892	4,110	21,924
1990	-	-	-	-	-	1,587	-	732	2,291	-	-	-	4,610
1991	-	-	-	-	730	-	1,835	-	2,940	-	-	-	5,504
1992	-	-	-	-	-	1,654	-	-	5,439	1,936	946	-	9,975
1993	-	-	-	-	-	-	-	2,791	3,747	1,595	-	-	8,132
1994	-	-	-	-	2,237	1,502	2,118	-	3,090	3,626	708	-	13,282
1995	-	-	-	-	2,904	551	1,553	2,874	13,103	7,147	5,427	2,392	35,951
1996	-	-	-	30	899	5,417	6,323	2,005	9,358	4,739	-	-	28,771
1997	-	-	-	-	3,055	5,964	2,001	551	12,165	3,015	1,908	1,265	29,925
1998	-	-	-	-	-	355	2,331	11,209	8,358	4,505	1,807	151	28,715
1999	-	-	-	-	-	-	-	5,407	13,141	7,865	139	-	26,551
2000													
2001													
2002	-	-	-	-	571	1,410	-	-	1,435	-	-	-	3,416
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	3,191	-	-	1,339	4,068	50	-	8,648
2005	-	-	-	-	-	-	-	5,334	7,970	420	157	-	13,880
2006	-	-	79	-	-	-	-	214	4,881	835	2,507	357	8,873
2007	-	-			3,245	2,424	1,890	2,110	15,523	5,873			31,066
2008		1,008	1,027	2,652	5,776	3,039			14,511	2,755			30,768
2009				4,401	4,028	1,781	61	1,704	14,267	5,651			31,895
2010	-	-	2	-	-	6,940	5,264	4,265	18,794	1,472	-	-	36,737
2011													
Mean	78	39	44	272	1,041	2,543	1,847	2,616	7,871	3,730	1,160	1,337	22,116

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Great Eastern Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	-	-	5,219	2,128	5,304	498	-	13,149
1983	-	-	-	-	-	4,013	5,104	3,937	5,250	7,383	5,550	1,297	32,533
1984	-	-	-	1,581	3,239	-	-	11,639	9,394	5,050	6,901	2,985	40,789
1985	-	-	-	-	3,142	4,501	-	5,236	6,000	4,947	2,414	-	26,240
1986	-	-	4,217	-	1,555	9,161	5,655	3,102	6,492	7,631	2,214	1,882	41,908
1987	-	-	-	-	2,152	936	3,818	2,471	2,184	7,256	774	-	19,591
1988	4,219	-	-	-	2,344	3,485	3,340	2,854	11,607	8,965	1,484	1,166	39,465
1989	-	-	-	664	4,794	422	4,752	1,349	119	6,647	-	256	19,004
1990	2,208	1,240	-	-	1,740	1,240	-	1,617	3,606	1,440	-	-	13,089
1991	2,563	1,105	-	3,326	827	-	-	496	7,313	-	-	-	15,630
1992	-	1,985	1,936	3,628	-	-	-	649	4,251	2,894	-	-	15,342
1993	-	-	-	1,287	6,204	-	1,517	-	5,411	958	1,422	1,307	18,107
1994	-	-	1,327	1,912	482	1,198	914	4,655	5,151	125	1,091	714	17,570
1995	2,154	1,470	-	2,148	605	2,073	766	1,168	5,903	623	3,822	-	20,732
1996	-	-	-	2,975	6,299	4,528	4,663	1,803	6,734	2,239	-	-	29,242
1997	-	-	-	2,269	2,408	2,797	599	2,059	6,609	1,829	756	30	19,355
1998	-	3,374	-	-	-	1,666	3,503	6,385	6,153	-	-	-	21,081
1999	-	-	3,392	-	-	522	2,129	3,370	6,258	2,398	968	-	19,037
2000													
2001													
2002	-	-	3,223	1,213	1,993	1	1,068	2,175	551	-	-	-	10,224
2003	-	-	690	1,875	2,753	578	-	3,853	511	-	-	-	10,260
2004	-	-	-	-	-	4,429	-	4,683	843	-	766	-	10,721
2005	-	-	1,732	3,765	3,842	549	1,785	5,935	6,542	175	157	-	24,480
2006	-	-	1,433	1,596	2	1	0	0	6,520	708	1,464	3,697	15,422
2007	4,444	-											4,444
2008													-
2009													-
2010													-
2011													-
Mean	649	382	780	1,228	1,930	1,830	1,722	3,246	5,023	2,894	1,316	580	17,765

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Combined Amazon Great Eastern Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	1,803	143	-	5,324	5,074	5,304	498	4,915	23,060
1983	-	-	-	-	-	4,013	8,821	5,558	9,487	12,522	8,366	4,326	53,092
1984	1,676	-	-	1,581	3,833	4,990	3,086	14,563	17,219	9,215	10,760	7,878	74,803
1985	-	-	-	-	3,142	7,694	5,617	14,333	14,359	11,145	4,352	-	60,642
1986	-	-	4,217	-	2,940	20,711	11,125	7,387	14,537	15,582	4,249	1,882	82,630
1987	-	-	-	-	2,152	2,785	9,453	7,910	12,056	15,701	2,432	4,941	57,430
1988	4,503	-	-	-	2,344	11,566	4,471	7,480	23,616	17,876	1,484	7,200	80,539
1989	-	-	-	664	5,673	3,463	4,752	2,083	6,992	11,042	1,892	4,366	40,928
1990	2,208	1,240	-	-	1,740	2,826	-	2,348	5,897	1,440	-	-	17,699
1991	2,563	1,105	-	3,326	1,557	-	1,835	496	10,253	-	-	-	21,134
1992	-	1,985	1,936	3,628	-	1,654	-	649	9,689	4,830	946	-	25,317
1993	-	-	-	1,287	6,204	-	1,517	2,791	9,158	2,553	1,422	1,307	26,240
1994	-	-	1,327	1,912	2,719	2,700	3,033	4,655	8,241	3,751	1,799	714	30,851
1995	2,154	1,470	-	2,148	3,509	2,624	2,319	4,042	19,006	7,769	9,249	2,392	56,682
1996	-	-	-	3,005	7,197	9,945	10,987	3,808	16,092	6,978	-	-	58,013
1997	-	-	-	2,269	5,463	8,761	2,600	2,610	18,774	4,844	2,664	1,295	49,280
1998	-	3,374	-	-	-	2,021	5,833	17,594	14,511	4,505	1,807	151	49,796
1999	-	-	3,392	-	-	522	2,129	8,777	19,399	10,263	1,107	-	45,588
2000													
2001													
2002	-	-	3,223	1,213	2,565	1,411	1,068	2,175	1,985	-	-	-	13,641
2003	-	-	690	1,875	2,753	578	-	3,853	511	-	-	-	10,260
2004	-	-	-	-	-	7,621	-	4,683	2,182	4,068	815	-	19,369
2005	-	-	1,732	3,765	3,842	549	1,785	11,268	14,511	594	313	-	38,360
2006	-	-	1,513	1,596	2	1	0	214	11,400	1,543	3,971	4,054	24,295
2007	4,444	-	-	-	3,245	2,424	1,890	2,110	15,523	5,873	-	-	35,510
2008	-	1,008	1,027	2,652	5,776	3,039	-	-	14,511	2,755	-	-	30,768
2009	-	-	-	4,401	4,028	1,781	61	1,704	14,267	5,651	-	-	31,895
2010	-	-	2	-	-	6,940	5,264	4,265	18,794	1,472	-	-	36,737
2011													
Mean	650	377	706	1,308	2,685	4,102	3,246	5,284	12,150	6,195	2,153	1,682	40,539

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Southside Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	-	-	-	518	2,737	-	706	3,961
1983	946	2,089	-	-	-	-	-	1,408	2,741	5,758	3,541	2,930	19,413
1984	1,434	-	-	-	-	-	-	2,838	4,451	3,180	5,712	4,056	21,672
1985	-	-	-	-	-	2,368	1,900	6,296	5,988	3,658	-	-	20,210
1986	-	-	-	-	-	7,512	2,227	2,610	6,587	3,219	3,310	-	25,466
1987	-	-	-	-	-	587	5,227	540	4,879	5,716	1,652	3,066	21,668
1988	1,051	-	-	-	-	879	3,552	920	5,451	8,579	1,022	1,728	23,181
1989	728	-	-	-	-	605	1,511	-	63	2,743	-	1,583	7,234
1990	692	-	-	-	-	649	1,377	1,252	2,662	-	-	-	6,631
1991	-	-	-	-	-	-	34	1,267	3,078	-	-	-	4,379
1992	-	-	-	-	-	-	-	-	-	4,530	2,358	2,904	9,793
1993	1,432	-	-	-	-	-	-	161	2,325	2,987	2,337	-	9,241
1994	-	-	-	-	-	-	1,597	-	2,838	1,783	1,993	2,021	10,233
1995	1,168	-	-	-	-	-	-	-	1,864	2,398	4,084	4,036	13,551
1996	1,388	-	-	-	246	3,616	3,152	1,488	3,747	3,007	-	1,202	17,846
1997	-	-	-	-	631	1,783	1,803	-	3,953	1,327	2,033	2,142	13,672
1998	-	-	-	-	-	-	776	3,152	3,249	2,055	1,442	133	10,806
1999	-	-	-	-	-	-	-	2,263	4,165	3,634	1,557	-	11,619
2000													
2001													
2002	-	-	-	-	141	1,959	-	662	42	-	-	-	2,803
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	1,539	-	-	-	-	-	-	1,539
2005	-	-	-	-	-	-	-	1,890	1,464	1,533	-	-	4,888
2006	-	-	-	-	-	396	395	-	-	-	-	-	790
2007	-	-					1,474	3,496	2,112	1,072	252		8,406
2008							145	1,507	2,733	4,320	517		9,222
2009								1,353	4,679	3,825	1,966		11,823
2010								2,886	5,391	5,405	-		13,682
2011								551	3,287	1,891	359		6,088
Mean	368	87	-	-	44	952	1,007	1,305	2,795	2,691	1,219	1,152	11,065

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Farmers Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	-	-	-	3,902	-	3,130	1,031	8,063
1983	1,301	861	-	139	2,055	-	3,170	-	1,615	5,677	4,088	3,860	22,765
1984	1,293	-	-	-	-	-	1,678	3,800	4,054	4,038	4,915	1,087	20,866
1985	-	-	-	-	-	3,495	1,295	3,993	4,368	1,823	1,152	-	16,126
1986	-	-	-	-	1,793	3,548	4,066	3,733	1,956	4,374	3,632	-	23,102
1987	-	-	-	-	-	294	4,743	2,434	1,716	5,399	4,743	1,063	20,390
1988	789	-	-	-	137	5,018	2,394	101	3,802	4,947	2,051	1,914	21,154
1989	764	-	-	-	712	1,970	2,176	666	1,680	3,261	421	1,496	13,145
1990	345	-	-	-	-	738	3,418	2,049	1,976	1,289	-	540	10,354
1991	1,531	-	-	-	1,325	1,722	883	871	728	1,244	-	-	8,303
1992	-	-	-	-	1,749	651	-	419	3,429	24	-	-	6,272
1993	1,230	-	-	-	-	-	2,362	2,771	5,310	2,388	589	-	14,650
1994	-	-	-	-	258	2,269	-	3,186	5,304	4,572	1,263	1,039	17,891
1995	1,613	-	-	-	63	2,481	1,111	3,765	4,754	4,116	4,169	365	22,437
1996	801	-	-	-	236	5,784	2,545	2,616	6,070	208	-	791	19,052
1997	266	-	-	-	16	4,679	1,488	877	6,375	1,864	3,477	1,043	20,085
1998	-	-	-	-	-	-	3,632	5,037	5,092	791	4,891	-	19,443
1999	-	-	-	-	-	-	-	2,731	4,201	4,673	2,124	95	13,825
2000													
2001													
2002	-	-	-	-	2	588	1,471	-	613	-	-	-	2,675
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	12	110	403	27	-	-	553
2005	-	-	-	-	-	56	4,408	731	1,487	-	-	-	6,681
2006	-	-	-	-	80	37	-	-	-	-	-	-	117
2007	-	-				3,276	3,392	1,769	3,554	271	1,428	635	14,326
2008	225					20	572		114	1,093	898	1,387	4,309
2009	2,109					723	901	1,230	1,543	1,519	937	578	9,540
2010								381	2,559	2,210	-	-	5,150
2011									1,360	655			2,015
Mean	472	36	-	6	366	1,436	1,758	1,664	2,784	2,017	1,626	627	12,260

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Garden City Ditch Diversion

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	-	-	-	-	-	-	510	-	510
1983	411	129	-	-	-	-	-	-	208	795	635	413	2,590
1984	52	-	-	-	-	-	11	611	559	549	551	91	2,425
1985	-	-	-	-	-	411	117	543	587	115	321	-	2,095
1986	-	-	-	-	121	520	381	240	518	645	518	278	3,219
1987	-	-	-	-	-	-	428	214	452	460	803	432	2,791
1988	107	-	-	-	-	373	345	274	633	629	87	202	2,650
1989	143	-	-	-	-	337	240	60	232	363	93	268	1,736
1990	4	-	-	-	-	-	79	347	284	266	292	436	1,708
1991	18	-	-	-	-	545	105	12	194	387	149	-	1,410
1992	-	-	-	-	-	333	228	165	282	85	-	155	1,248
1993	28	-	-	-	-	-	89	323	512	230	111	-	1,293
1994	-	-	-	-	-	258	179	559	454	440	212	377	2,479
1995	111	-	-	-	-	385	-	196	1,573	583	256	28	3,132
1996	4	-	-	-	-	595	387	182	1,105	613	-	-	2,886
1997	-	-	-	-	97	674	194	127	875	155	313	264	2,700
1998	-	-	-	-	-	119	171	637	573	58	95	-	1,652
1999	-	-	-	-	-	-	-	153	712	351	149	-	1,365
2000													
2001													
2002	2	-	-	-	-	83	231	-	140	-	-	-	456
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	86	108	-	-	194
2005	-	-	-	-	-	-	-	-	206	-	-	-	206
2006	-	-	-	-	245	13	-	-	-	-	-	-	258
2007	-	-											
2008													
2009													
2010													
2011													
Mean	37	5	-	-	20	202	138	202	443	297	222	128	1,696

Source: Tabulation provided by KDWR

Note: 2000 & 2001 data removed due to incomplete data

Total Ditch Diversions

Total Monthly Flow, Acre-Feet

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1982	-	-	-	-	1,803	143	-	5,324	9,493	8,041	4,138	6,653	35,594
1983	2,658	3,078	-	139	2,055	4,013	11,990	6,966	14,051	24,752	16,630	11,528	97,860
1984	4,455	-	-	1,581	3,833	4,990	4,775	21,813	26,283	16,983	21,939	13,113	119,766
1985	-	-	-	-	3,142	13,968	8,930	25,165	25,302	16,741	5,826	-	99,072
1986	-	-	4,217	-	4,854	32,290	17,800	13,970	23,598	23,820	11,709	2,160	134,417
1987	-	-	-	-	2,152	3,666	19,851	11,098	19,103	27,277	9,630	9,503	102,279
1988	6,450	-	-	-	2,481	17,836	10,762	8,775	33,501	32,031	4,643	11,044	127,524
1989	1,634	-	-	664	6,385	6,375	8,680	2,809	8,967	17,409	2,406	7,712	63,042
1990	3,249	1,240	-	-	1,740	4,213	4,873	5,996	10,818	2,995	292	976	36,391
1991	4,112	1,105	-	3,326	2,882	2,267	2,856	2,646	14,253	1,630	149	-	35,227
1992	-	1,985	1,936	3,628	1,749	2,638	228	1,232	13,401	9,469	3,305	3,059	42,629
1993	2,690	-	-	1,287	6,204	-	3,969	6,046	17,304	8,158	4,459	1,307	51,424
1994	-	-	1,327	1,912	2,977	5,227	4,808	8,400	16,838	10,546	5,268	4,151	61,455
1995	5,046	1,470	-	2,148	3,572	5,490	3,429	8,003	27,198	14,866	17,758	6,821	95,803
1996	2,194	-	-	3,005	7,679	19,940	17,070	8,095	27,013	10,806	-	1,993	97,796
1997	266	-	-	2,269	6,206	15,898	6,085	3,614	29,977	8,190	8,487	4,745	85,737
1998	-	3,374	-	-	-	2,140	10,411	26,419	23,425	7,408	8,235	284	81,697
1999	-	-	3,392	-	-	522	2,129	13,924	28,477	18,921	4,937	95	72,397
2000	-	-	-	-	-	-	-	-	-	-	-	-	
2001	-	-	-	-	-	-	-	-	-	-	-	-	
2002	2	-	3,223	1,213	2,708	4,041	2,770	2,838	2,781	-	-	-	19,575
2003	-	-	690	1,875	2,753	578	-	3,853	511	-	-	-	10,260
2004	-	-	-	-	-	9,159	12	4,793	2,671	4,204	815	-	21,655
2005	-	-	1,732	3,765	3,842	605	6,193	13,889	17,668	2,128	313	-	50,134
2006	-	-	1,513	1,596	326	447	395	214	11,400	1,543	3,971	4,054	25,461
2007	4,444	-	-	-	3,245	5,700	6,756	7,375	21,190	7,216	1,680	635	58,241
2008	225	1,008	1,027	2,652	5,776	3,059	717	1,507	17,359	8,168	1,415	1,387	44,299
2009	2,109	-	-	4,401	4,028	2,505	962	4,286	20,490	10,995	2,903	578	53,257
2010	-	-	2	-	-	6,940	5,264	7,531	26,744	9,087	-	-	55,569
2011	-	-	-	-	-	-	-	551	4,647	2,545	359	-	8,102
Mean	1,318	442	635	1,182	2,746	5,822	5,391	7,571	16,482	10,198	4,709	3,060	63,809

Source: KDWR diversion records for Amazon, Great Eastern, South Side, Farmers, and Garden City Ditches

Note: 2000 & 2001 data removed due to incomplete data

Appendix C

Stream Loss Analysis

Summer

Winter

GMD3 System Optimization Study

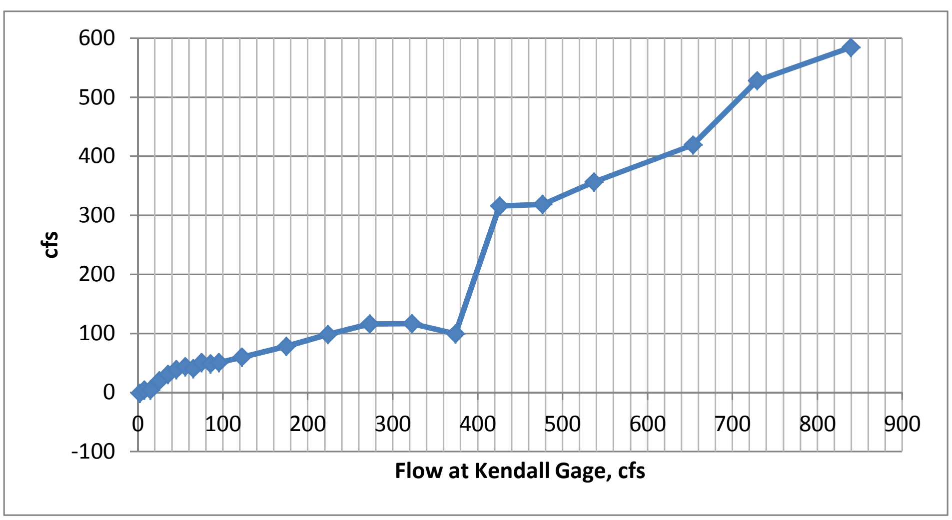
Kendall - Deerfield Reach - Summer

Flow Range, cfs	Avg Flow at Kendall, cfs	Avg Flow at Deerfield, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.2	3.4	-1.2	0.0	-60%
5-10	7.7	3.6	4.1	0.2	52%
10-20	15.0	10.7	4.3	0.2	31%
20-30	25.3	5.3	20.0	0.7	79%
30-40	35.4	4.7	30.7	1.1	87%
40-50	45.3	6.7	38.6	1.4	85%
50-60	55.8	12.0	43.7	1.6	79%
60-70	65.4	25.3	40.1	1.5	61%
70-80	75.2	24.5	50.7	1.9	67%
80-90	85.7	37.3	48.4	1.8	57%
90-100	95.3	44.6	50.7	1.9	53%
100-150	122.5	62.9	59.6	2.2	49%
150-200	174.7	96.5	78.2	2.9	44%
200-250	223.6	125.5	98.0	3.6	44%
250-300	273.0	156.8	116.2	4.3	42%
300-350	322.6	205.9	116.7	4.3	36%
350-400	373.8	274.7	99.1	3.7	26%
400-450	425.9	110.2	315.7	11.7	74%
450-500	476.4	158.2	318.2	11.8	67%
500-600	536.7	180.3	356.4	13.3	67%
600-700	653.6	234.5	419.1	15.6	64%
700-800	729.3	201.3	528.0	19.6	72%
800-900	839.5	255.5	584.0	21.7	69%

Kendall - Deerfield reach distance = 26.9 miles

Kendall - Deerfield Reach - Summer

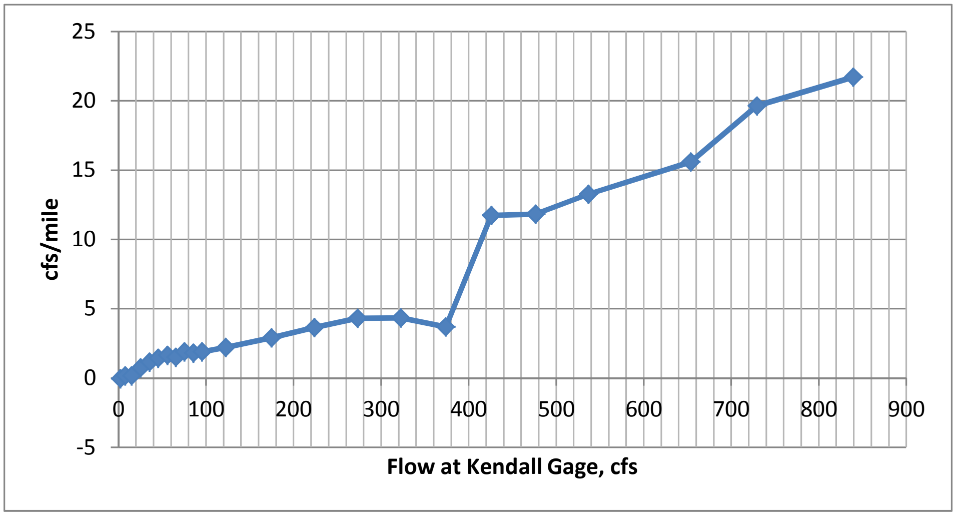
Stream Loss, cfs



GMD3 System Optimization Study

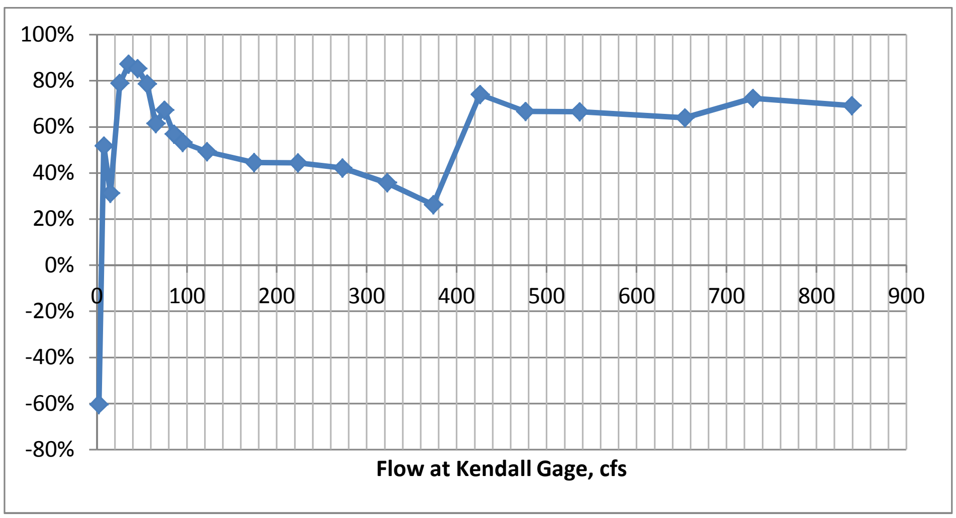
Kendall - Deerfield Reach - Summer

Stream Loss, cfs/mile



Kendall - Deerfield Reach - Summer

Stream Loss, %

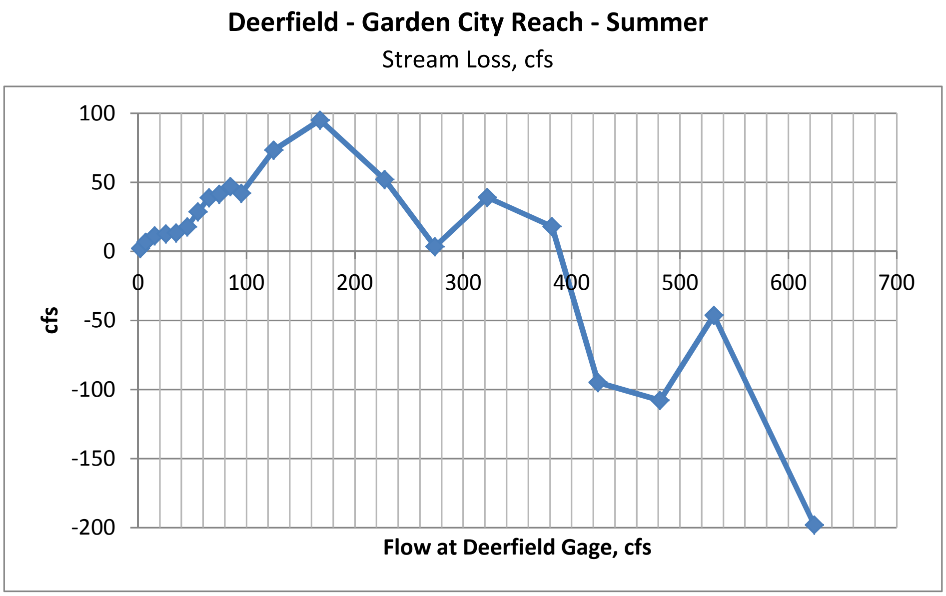


GMD3 System Optimization Study

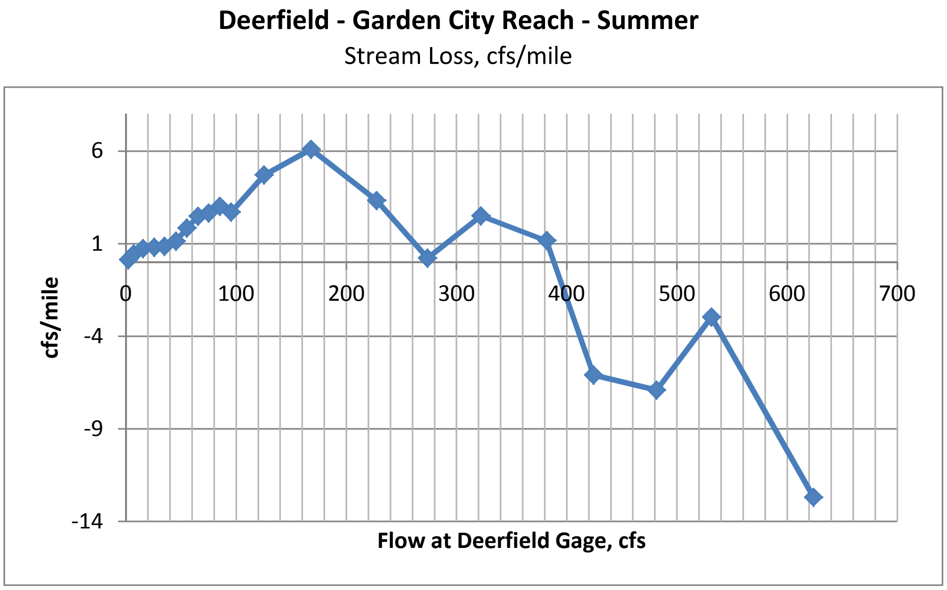
Deerfield - Garden City Reach - Summer

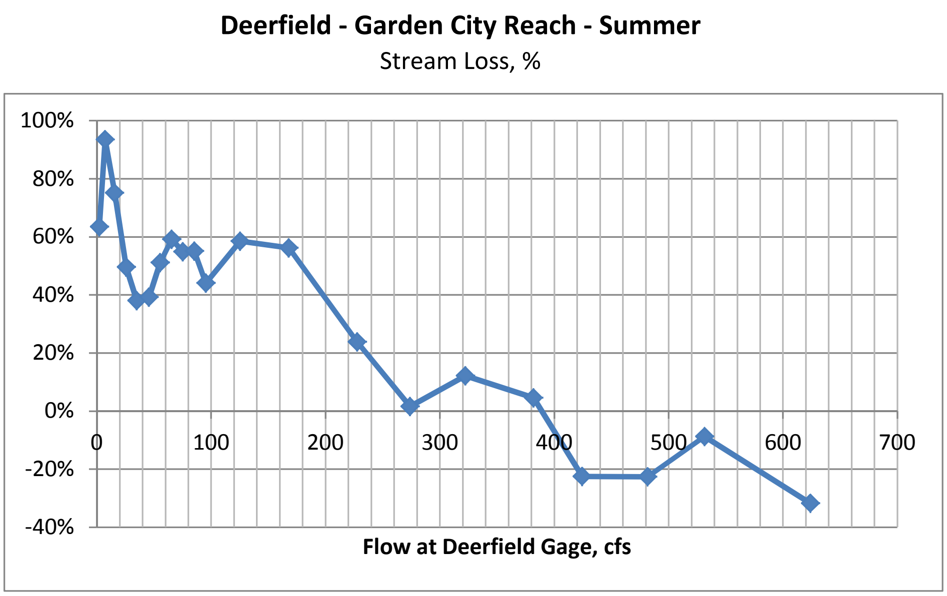
Flow Range, cfs	Avg Flow at Deerfield, cfs	Avg Flow at Garden City, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.2	0.1	2.0	0.1	63%
5-10	7.3	0.0	6.8	0.4	94%
10-20	15.6	0.1	11.4	0.7	75%
20-30	25.7	0.1	12.6	0.8	50%
30-40	35.1	0.6	13.4	0.9	38%
40-50	45.5	0.7	17.8	1.1	39%
50-60	55.3	0.1	28.6	1.8	51%
60-70	65.5	2.4	38.8	2.5	59%
70-80	75.1	1.5	41.3	2.7	55%
80-90	85.4	1.6	47.0	3.0	55%
90-100	95.4	4.9	42.1	2.7	44%
100-150	125.3	27.2	73.4	4.7	59%
150-200	168.0	52.9	95.1	6.1	56%
200-250	227.6	162.5	52.0	3.3	24%
250-300	273.8	258.4	3.4	0.2	2%
300-350	322.3	279.3	39.0	2.5	12%
350-400	381.8	358.2	18.1	1.2	5%
400-450	424.3	519.3	-95.0	-6.1	-22%
450-500	481.6	589.4	-107.8	-6.9	-23%
500-600	531.3	577.7	-46.3	-3.0	-9%
600-700	624.0	822.0	-198.0	-12.7	-32%

Deerfield - Garden City reach distance = 15.6 miles



GMD3 System Optimization Study



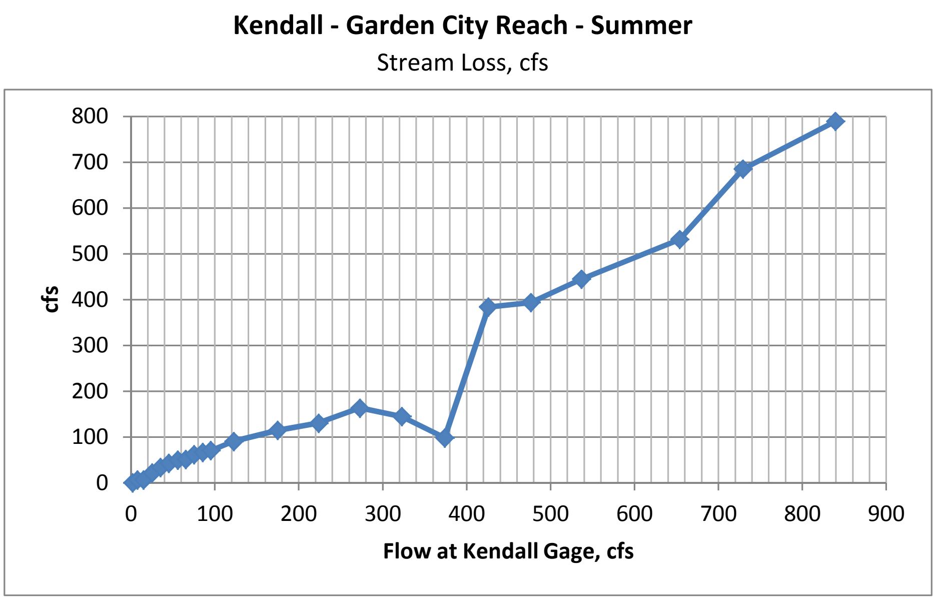


GMD3 System Optimization Study

Kendall - Garden City Reach - Summer

Flow Range, cfs	Avg Flow at Kendall, cfs	Avg Flow at Garden City, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.2	2.1	0.1	0.0	2%
5-10	7.7	1.0	6.7	0.2	87%
10-20	15.0	8.3	6.7	0.2	47%
20-30	25.3	3.3	22.0	0.5	87%
30-40	35.4	2.0	33.4	0.8	95%
40-50	45.3	2.9	42.4	1.0	94%
50-60	55.8	5.9	49.8	1.2	90%
60-70	65.4	14.2	51.2	1.2	78%
70-80	75.2	13.3	61.9	1.5	82%
80-90	85.7	18.9	66.8	1.6	78%
90-100	95.3	24.6	70.7	1.7	74%
100-150	122.5	32.0	90.5	2.1	74%
150-200	174.7	60.1	114.6	2.7	66%
200-250	223.6	93.3	130.3	3.1	59%
250-300	273.0	109.8	163.2	3.8	59%
300-350	322.6	178.0	144.7	3.4	44%
350-400	373.8	275.7	98.1	2.3	26%
400-450	425.9	41.9	384.0	9.0	90%
450-500	476.4	82.8	393.6	9.3	82%
500-600	536.7	92.0	444.8	10.5	83%
600-700	653.6	122.2	531.5	12.5	81%
700-800	729.3	43.9	685.4	16.1	94%
800-900	839.5	50.1	789.4	18.6	94%

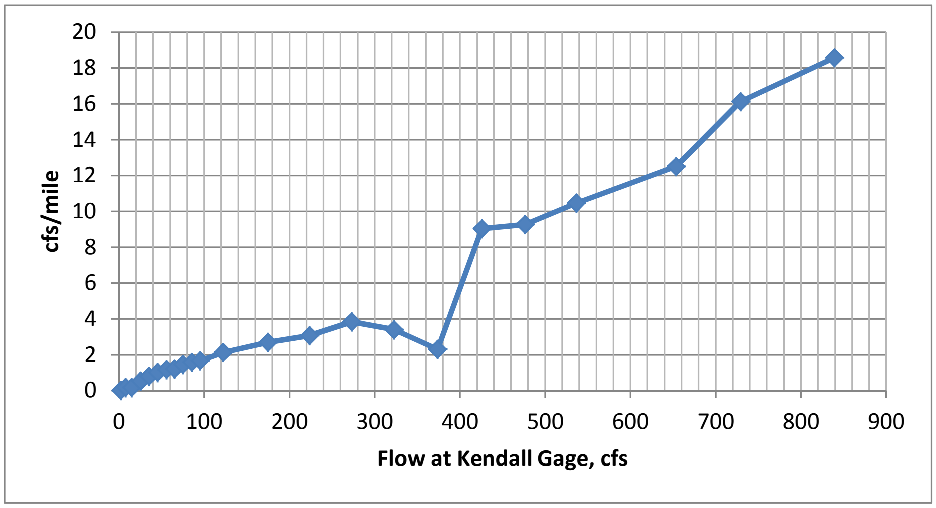
Kendall - Garden City reach distance = 42.5 miles



GMD3 System Optimization Study

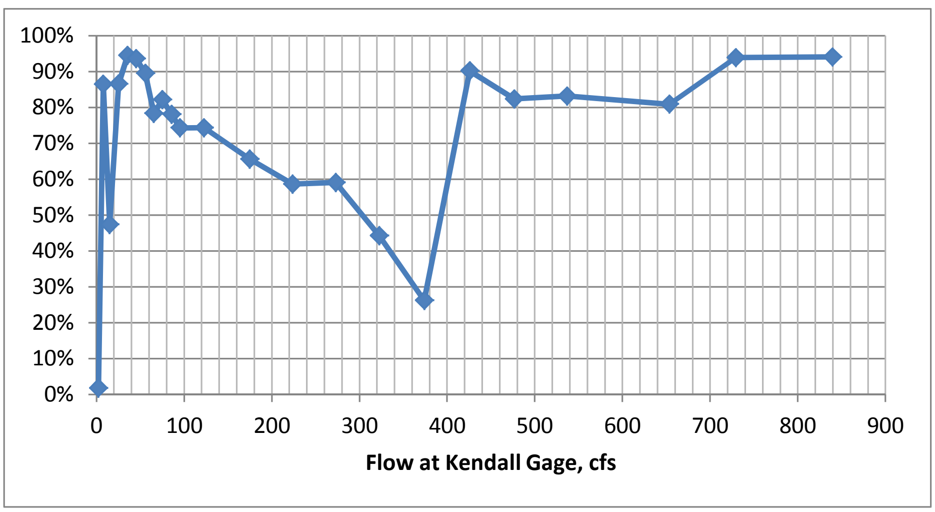
Kendall - Garden City Reach - Summer

Stream Loss, cfs/mile



Kendall - Garden City Reach - Summer

Stream Loss, %

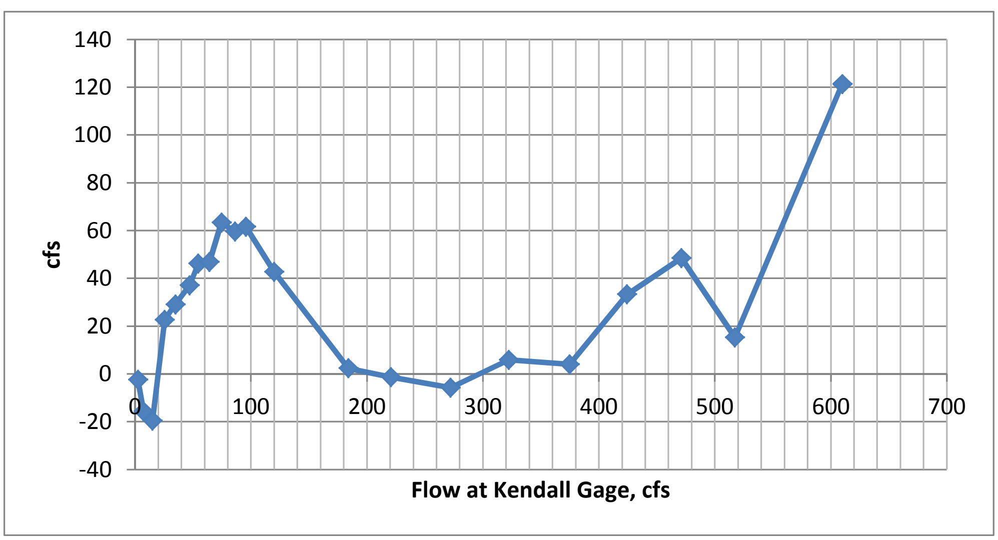


GMD3 System Optimization Study

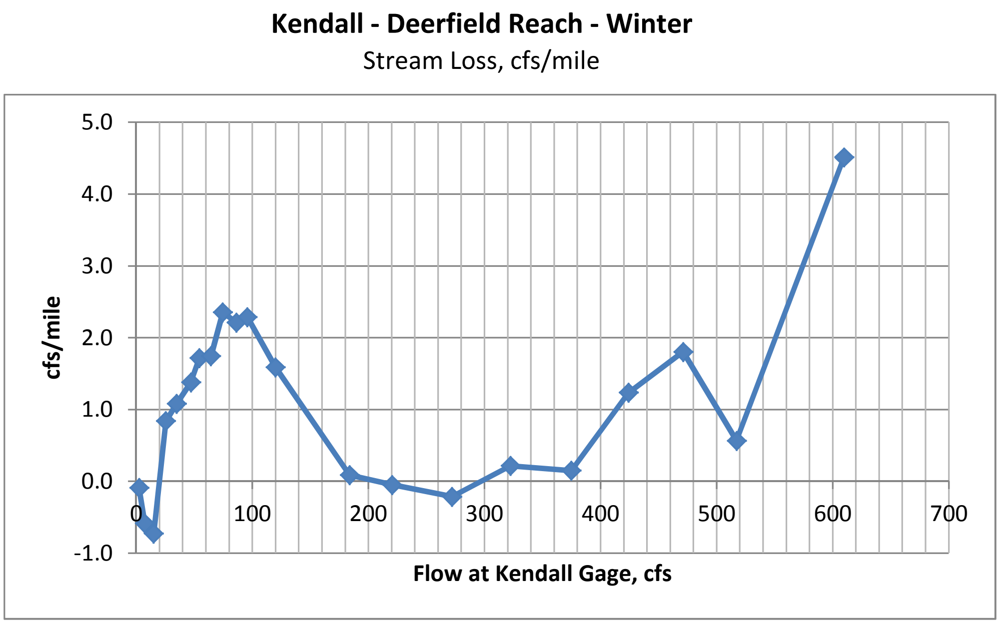
Kendall - Deerfield Reach - Winter

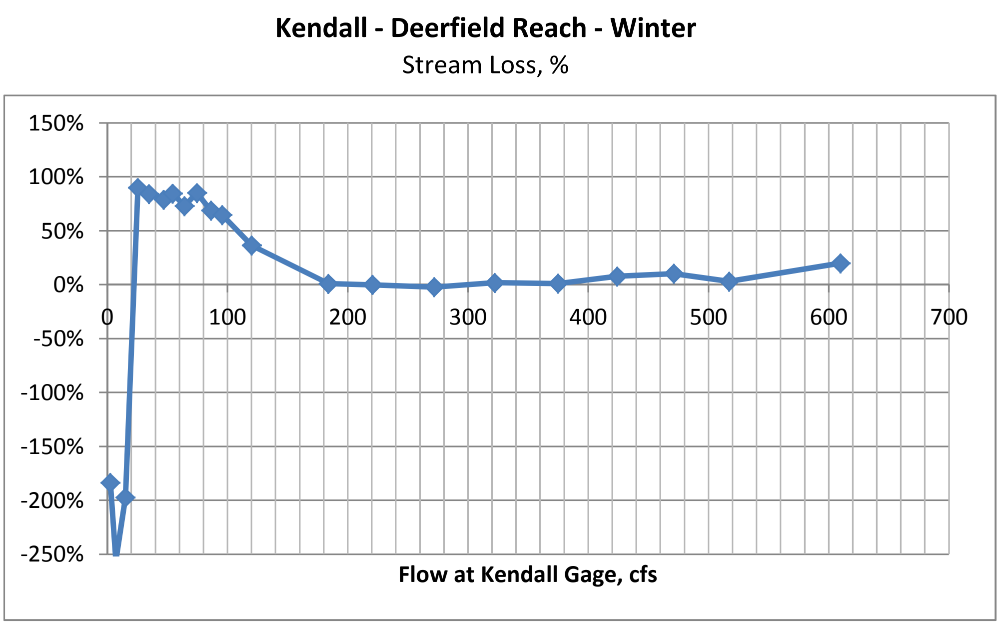
Flow Range, cfs	Avg Flow at Kendall, cfs	Avg Flow at Deerfield, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.5	5.0	-2.5	-0.1	-184%
5-10	7.2	23.0	-15.7	-0.6	-256%
10-20	15.0	34.6	-19.6	-0.7	-197%
20-30	25.6	3.0	22.6	0.8	90%
30-40	34.8	5.7	29.1	1.1	84%
40-50	47.1	10.1	37.1	1.4	79%
50-60	54.5	8.4	46.2	1.7	85%
60-70	64.3	17.4	46.9	1.7	73%
70-80	74.6	11.2	63.3	2.4	85%
80-90	86.3	26.7	59.5	2.2	69%
90-100	95.8	34.2	61.5	2.3	65%
100-150	120.1	77.4	42.7	1.6	36%
150-200	184.0	181.7	2.3	0.1	1%
200-250	220.6	221.9	-1.3	0.0	0%
250-300	272.1	277.8	-5.8	-0.2	-2%
300-350	322.4	316.6	5.8	0.2	2%
350-400	374.8	370.8	4.1	0.2	1%
400-450	424.2	390.9	33.3	1.2	8%
450-500	471.2	422.7	48.5	1.8	10%
500-600	517.2	502.0	15.2	0.6	3%
600-700	609.8	488.5	121.3	4.5	20%

Kendall - Deerfield reach distance = 26.9 miles



GMD3 System Optimization Study



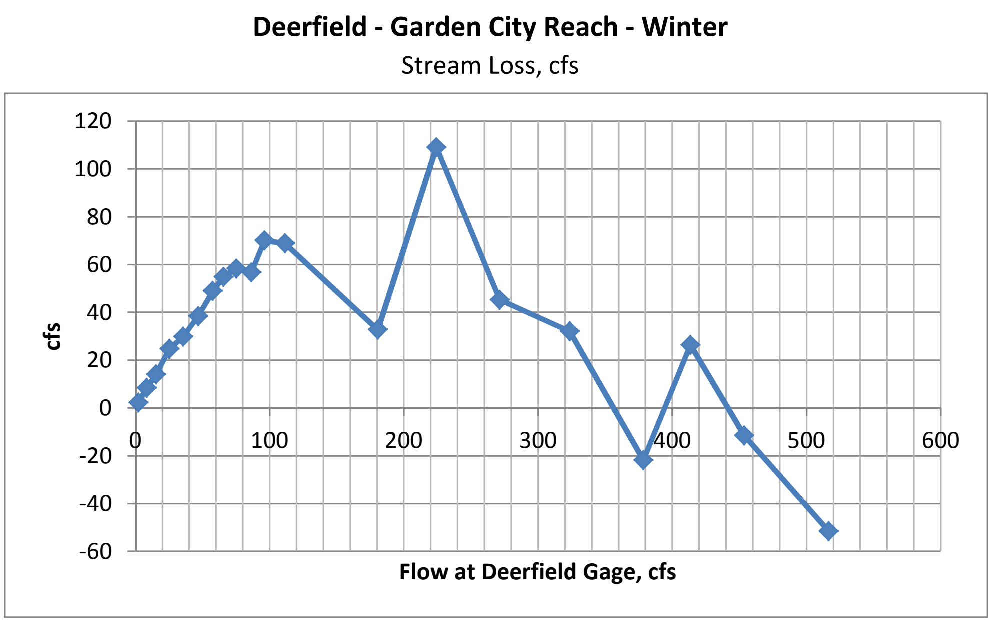


GMD3 System Optimization Study

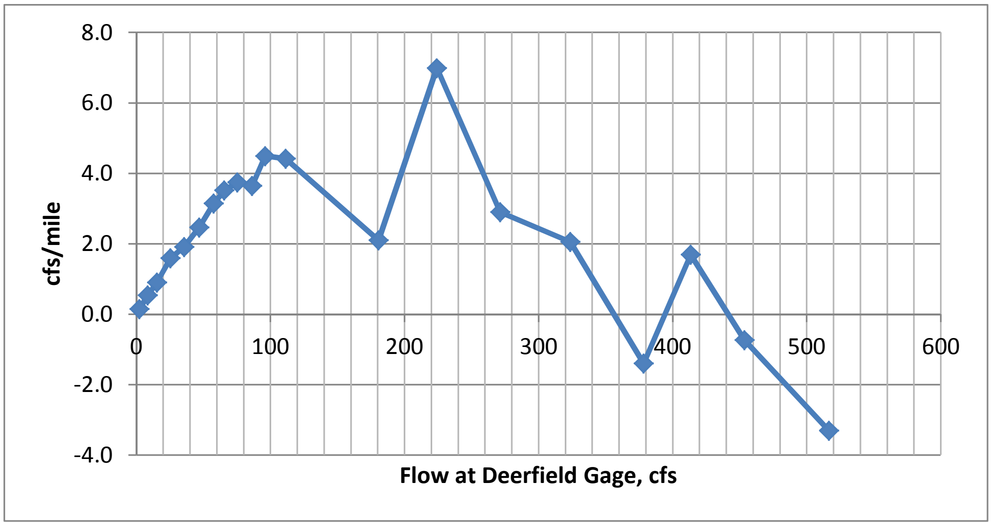
Deerfield - Garden City Reach - Winter

Flow Range, cfs	Avg Flow at Deerfield, cfs	Avg Flow at Garden City, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.3	0.0	2.3	0.1	100%
5-10	8.4	0.0	8.4	0.5	100%
10-20	15.4	0.1	14.1	0.9	92%
20-30	25.4	0.6	24.8	1.6	98%
30-40	35.6	4.8	29.8	1.9	84%
40-50	46.8	7.4	38.5	2.5	82%
50-60	57.7	8.5	49.0	3.1	85%
60-70	65.6	5.0	54.9	3.5	84%
70-80	75.3	8.7	58.4	3.7	77%
80-90	86.4	29.6	56.8	3.6	66%
90-100	96.2	26.1	70.1	4.5	73%
100-150	111.4	42.6	68.9	4.4	62%
150-200	180.6	147.8	32.7	2.1	18%
200-250	224.1	115.1	109.1	7.0	49%
250-300	271.3	226.1	45.2	2.9	17%
300-350	323.6	291.6	32.1	2.1	10%
350-400	378.4	400.2	-21.8	-1.4	-6%
400-450	413.5	387.1	26.4	1.7	6%
450-500	453.5	465.0	-11.5	-0.7	-3%
500-600	516.5	568.0	-51.5	-3.3	-10%

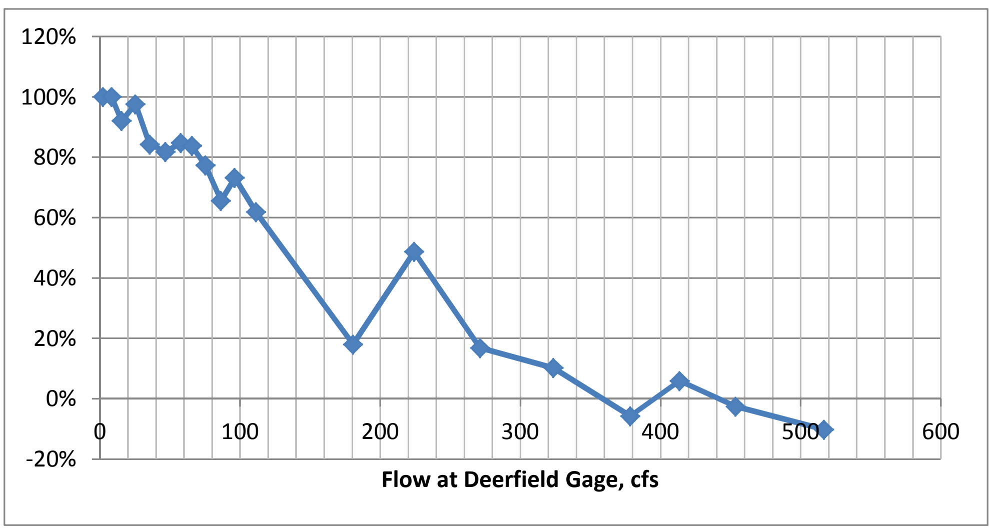
Deerfield - Garden City reach distance = 15.6 miles



Deerfield - Garden City Reach - Winter
Stream Loss, cfs/mile



Deerfield - Garden City Reach - Winter
Stream Loss, %



GMD3 System Optimization Study

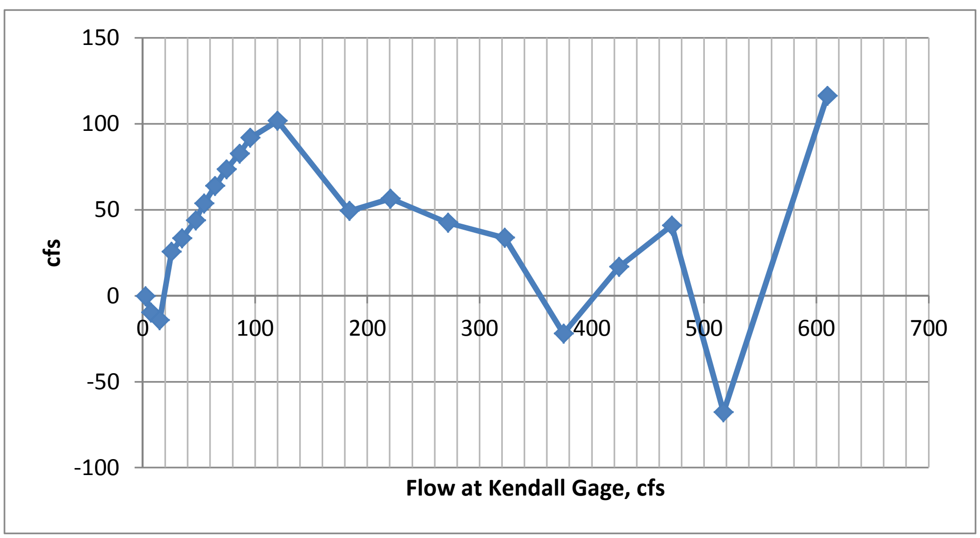
Kendall - Garden City Reach - Winter

Flow Range, cfs	Avg Flow at Kendall, cfs	Avg Flow at Garden City, cfs	Stream Loss, cfs	Stream Loss, cfs/mile	Stream Loss, %
0-5	2.5	2.9	-0.3	0.0	-84%
5-10	7.2	16.9	-9.7	-0.2	-156%
10-20	15.0	29.3	-14.2	-0.3	-167%
20-30	25.6	0.0	25.6	0.6	100%
30-40	34.8	1.4	33.4	0.8	96%
40-50	47.1	3.3	43.8	1.0	93%
50-60	54.5	1.0	53.6	1.3	98%
60-70	64.3	0.6	63.8	1.5	99%
70-80	74.6	1.1	73.5	1.7	99%
80-90	86.3	3.6	82.7	1.9	96%
90-100	95.8	3.9	91.8	2.2	96%
100-150	120.1	18.4	101.7	2.4	85%
150-200	184.0	134.7	49.3	1.2	28%
200-250	220.6	164.3	56.4	1.3	26%
250-300	272.1	229.7	42.4	1.0	16%
300-350	322.4	288.7	33.7	0.8	11%
350-400	374.8	396.9	-22.1	-0.5	-6%
400-450	424.2	407.5	16.7	0.4	4%
450-500	471.2	430.3	40.8	1.0	9%
500-600	517.2	585.0	-67.8	-1.6	-13%
600-700	609.8	493.5	116.3	2.7	19%

Kendall - Garden City reach distance = 42.5 miles

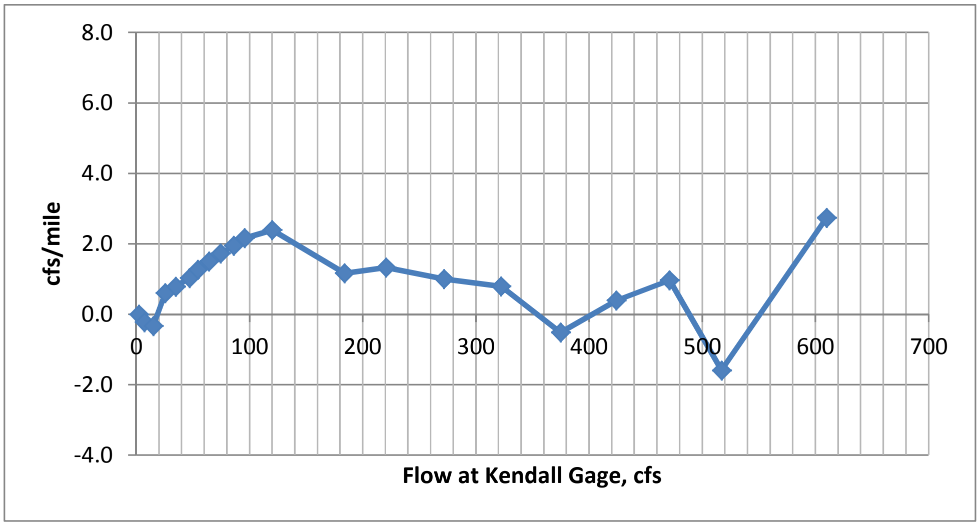
Kendall - Garden City Reach - Winter

Stream Loss, cfs

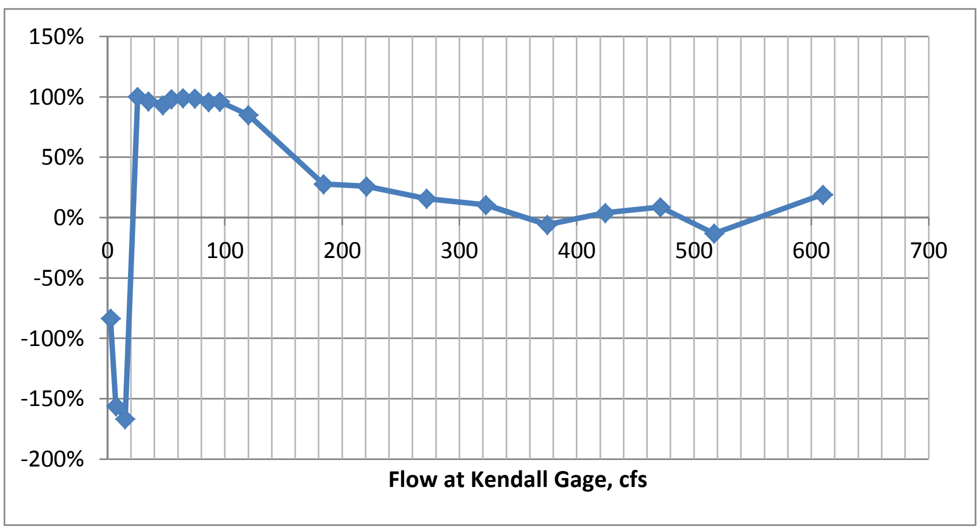


GMD3 System Optimization Study

Kendall - Garden City Reach - Winter
Stream Loss, cfs/mile



Kendall - Garden City Reach - Winter
Stream Loss, %



Appendix D

Bear Creek Valley Recharge Yield Analysis and Sensitivity Runs

Parameters for Bear Creek Valley Recharge Yield Analysis

Baseline:

- Minimum Bypass Requirement:
  - Summer = 500 cfs
  - Winter = 100 cfs
- Minimum Flow in River Channel to Allow Flow to be Diverted = 100 cfs
- Diversion Capacity = 700 cfs

Sensitivity I:

- Minimum Bypass Requirement:
  - Summer = 500 cfs
  - Winter = 100 cfs
- Minimum Flow in River Channel to Allow Flow to be Diverted = 100 cfs
- Diversion Capacity = 500 cfs

Sensitivity II:

- Minimum Bypass Requirement:
  - Summer = 500 cfs
  - Winter = 200 cfs
- Minimum Flow in River Channel to Allow Flow to be Diverted = 100 cfs
- Diversion Capacity = 700 cfs

Sensitivity III:

- Minimum Bypass Requirement:
  - Summer = 400 cfs
  - Winter = 100 cfs
- Minimum Flow in River Channel to Allow Flow to be Diverted = 100 cfs
- Diversion Capacity = 700 cfs

Bear Creek Valley Recharge Diversion
Total Divertable Flow Summary
Acre-Feet

Year	Divertable Flow					
	(1)	(2)	(3)	(4)	(5)	(6)
1982	-	-	-	-	-	-
1983	-	-	-	-	1,045	-
1984	-	-	-	-	5,929	-
1985	14,493	14,111	12,277	11,769	30,925	16,158
1986	5,616	5,405	4,010	3,480	23,182	7,171
1987	126,180	99,694	208,069	112,648	248,895	131,329
1988	17,624	17,624	4,450	718	29,418	18,657
1989	638	638	43	-	17,159	638
1990	-	-	-	-	6,454	-
1991	-	-	-	-	1,528	-
1992	-	-	-	-	154	-
1993	-	-	-	-	4,771	-
1994	-	-	-	-	10,326	-
1995	49,195	36,015	83,009	49,195	96,439	50,841
1996	16,681	15,819	12,989	9,829	41,211	21,845
1997	37,124	35,098	22,824	13,169	52,591	39,080
1998	157,620	133,920	145,218	134,946	181,789	162,380
1999	128,782	102,587	228,087	107,029	268,993	132,305
2000	55,997	55,958	30,384	22,354	60,624	57,756
2001	10,556	10,556	1,904	290	27,174	11,752
2002	-	-	-	-	5,431	-
2003	-	-	-	-	-	-
2004	-	-	-	-	-	-
2005	-	-	-	-	-	-
2006	-	-	-	-	-	-
2007	5,984	5,984	1,291	-	8,815	5,984
2008	-	-	-	-	1,714	-
2009	-	-	-	-	1,716	-
2010	-	-	-	-	9,547	-
2011	-	-	-	-	253	-
Mean	20,883	17,780	25,152	15,514	37,869	21,863
Max	157,620	133,920	228,087	134,946	268,993	162,380

Run Definition:

(1) Baseline Run with 700 cfs Capacity Restriction
(2) Sensitivity I with 500 cfs Capacity Restriction
(3) Sensitivity II with 200 cfs Winter Bypass and No Capacity Restriction
(4) Sensitivity II with 200 cfs Winter Bypass and 700 cfs Capacity Restriction
(5) Sensitivity III with 400 cfs Summer Bypass and No Capacity Restriction
(6) Sensitivity III with 400 cfs Summer Bypass and 700 cfs Capacity Restriction

Divertable Flow - No Capacity Restrictions

Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	485	349	211	-	-	-	-	-	-	-	1,045
1984	458	1,819	1,093	1,531	1,029	-	-	-	-	-	-	-	5,929
1985	5,520	4,372	2,173	3,084	2,098	-	990	11,076	-	66	-	-	29,378
1986	5,487	4,190	2,648	3,372	1,802	-	-	-	1,262	1,280	1,118	-	21,157
1987	7,661	5,983	5,130	4,847	8,834	33,028	70,850	88,064	10,632	-	-	-	235,031
1988	5,387	7,006	5,496	5,568	4,048	-	42	56	-	-	901	-	28,503
1989	4,192	5,258	3,440	2,682	1,315	-	-	-	-	-	-	-	16,887
1990	51	1,054	2,010	1,607	1,733	-	-	-	-	-	-	-	6,454
1991	80	153	844	451	-	-	-	-	-	-	-	-	1,528
1992	-	-	10	144	-	-	-	-	-	-	-	-	154
1993	-	132	532	1,800	2,307	-	-	-	-	-	-	-	4,771
1994	1,968	2,770	2,974	2,314	299	-	-	-	-	-	-	-	10,326
1995	1,318	2,886	2,941	1,694	1,571	-	-	1,955	73,423	7,631	-	-	93,420
1996	5,915	5,600	5,052	3,132	2,695	-	5,802	2,046	1,230	3,142	67	-	34,680
1997	8,784	8,330	7,219	4,246	2,942	-	-	-	-	16,721	-	-	48,242
1998	17,384	22,528	49,887	25,479	30,318	21,526	919	-	1,429	4,813	-	-	174,282
1999	11,098	6,609	5,488	5,513	6,060	-	102,199	91,870	7,637	19,347	-	-	255,821
2000	11,411	9,116	5,573	12,560	19,133	-	57	-	1,146	-	-	-	58,997
2001	7,145	5,875	5,276	2,686	4,538	-	143	351	-	-	-	-	26,014
2002	349	1,743	1,327	1,319	623	-	-	-	-	-	-	-	5,361
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	286	20	-	1,400	7,109	-	-	-	-	-	-	-	8,815
2008	14	567	813	290	30	-	-	-	-	-	-	-	1,714
2009	781	752	161	22	-	-	-	-	-	-	-	-	1,716
2010	2,696	1,692	1,801	1,472	1,886	-	-	-	-	-	-	-	9,547
2011	-	-	118	135	-	-	-	-	-	-	-	-	253
Mean	3,266	3,282	3,750	2,923	3,353	1,818	6,033	6,514	3,225	1,767	70	-	36,001
Max	17,384	22,528	49,887	25,479	30,318	33,028	102,199	91,870	73,423	19,347	1,118	-	255,821

Divertable Flow - 700 cfs Capacity Restriction

Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	2,511	-	-	213	-	-	990	10,779	-	-	-	-	14,493
1986	2,136	-	-	-	-	-	-	-	1,202	1,160	1,118	-	5,616
1987	7,661	2,729	-	425	6,183	31,001	29,467	40,836	7,878	-	-	-	126,180
1988	4,280	6,612	3,128	2,888	-	-	-	-	-	-	718	-	17,624
1989	200	-	-	438	-	-	-	-	-	-	-	-	638
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,722	41,613	5,860	-	-	49,195
1996	3,362	1,790	202	1,276	222	-	4,711	1,943	931	2,245	-	-	16,681
1997	8,784	8,330	6,432	409	-	-	-	-	-	13,169	-	-	37,124
1998	17,384	22,514	42,114	24,509	26,311	18,067	798	-	1,267	4,656	-	-	157,620
1999	11,098	4,018	5,298	2,143	2,924	-	40,849	41,208	6,413	14,831	-	-	128,782
2000	11,411	9,116	3,459	12,045	19,133	-	-	-	833	-	-	-	55,997
2001	6,750	2,702	-	615	200	-	-	290	-	-	-	-	10,556
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	5,984	-	-	-	-	-	-	-	5,984
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	2,519	1,927	2,021	1,499	2,032	1,636	2,561	3,226	2,005	1,397	61	-	20,883
Max	17,384	22,514	42,114	24,509	26,311	31,001	40,849	41,208	41,613	14,831	1,118	-	157,620

Diversion Frequency - 700 cfs Capacity Restriction

Days

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	12	-	-	1	-	-	3	17	-	-	-	-	33
1986	9	-	-	-	-	-	-	-	1	2	3	-	15
1987	30	13	-	2	13	29	22	30	9	-	-	-	148
1988	16	29	13	14	-	-	-	-	-	-	2	-	74
1989	1	-	-	2	-	-	-	-	-	-	-	-	3
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	2	30	6	-	-	38
1996	15	8	1	6	1	-	5	6	3	5	-	-	50
1997	30	31	27	2	-	-	-	-	-	14	-	-	104
1998	30	31	31	28	31	20	2	-	2	6	-	-	181
1999	30	17	24	9	13	-	30	30	7	17	-	-	177
2000	30	31	13	26	31	-	-	-	3	-	-	-	134
2001	28	13	-	3	1	-	-	1	-	-	-	-	46
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	25	-	-	-	-	-	-	-	25
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	8	6	4	3	4	2	2	3	2	2	0	-	34
Max	30	31	31	28	31	29	30	30	30	17	3	-	181

Divertable Flow - 1400 cfs Capacity Restriction

Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	2,511	-	-	213	-	-	990	10,779	-	-	-	-	14,493
1986	2,136	-	-	-	-	-	-	-	1,202	1,160	1,118	-	5,616
1987	7,661	2,729	-	425	6,183	33,028	55,328	74,986	10,131	-	-	-	190,472
1988	4,280	6,612	3,128	2,888	-	-	-	-	-	-	718	-	17,624
1989	200	-	-	438	-	-	-	-	-	-	-	-	638
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,722	73,316	7,575	-	-	82,614
1996	3,362	1,790	202	1,276	222	-	5,802	1,943	931	2,245	-	-	17,772
1997	8,784	8,330	6,432	409	-	-	-	-	-	16,627	-	-	40,582
1998	17,384	22,528	49,887	25,479	30,318	21,490	798	-	1,267	4,656	-	-	173,806
1999	11,098	4,018	5,298	2,143	2,924	-	77,527	73,675	7,637	19,012	-	-	203,331
2000	11,411	9,116	3,459	12,045	19,133	-	-	-	833	-	-	-	55,997
2001	6,750	2,702	-	615	200	-	-	290	-	-	-	-	10,556
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	5,984	-	-	-	-	-	-	-	5,984
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	2,519	1,928	2,280	1,531	2,165	1,817	4,681	5,446	3,177	1,709	61	-	27,316
Max	17,384	22,528	49,887	25,479	30,318	33,028	77,527	74,986	73,316	19,012	1,118	-	203,331

Maximum Daily Flow - 700 cfs Capacity Restriction

cfs

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mean Max
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	177	601	-	-	-	-	389
1986	153	-	-	-	-	-	-	-	-	-	-	-	153
1987	163	109	-	-	365	700	700	700	700	-	-	-	491
1988	139	128	136	111	-	-	-	-	-	-	-	-	129
1989	-	-	-	110	-	-	-	-	-	-	-	-	110
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	142	700	700	-	-	514
1996	139	126	102	112	-	-	700	222	177	433	-	-	251
1997	184	145	137	104	-	-	-	-	-	700	-	-	254
1998	397	650	700	700	700	700	230	-	416	597	-	-	566
1999	331	135	143	144	131	-	700	700	700	700	-	-	409
2000	249	198	156	363	510	-	-	-	171	-	-	-	274
2001	186	109	-	105	-	-	-	146	-	-	-	-	137
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	65	53	46	58	57	47	84	84	95	104	-	-	123
Max	397	650	700	700	700	700	700	700	700	700	-	-	566

Maximum Daily Flow - 1400 cfs Capacity Restriction

cfs

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mean Max
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	177	601	-	-	-	-	389
1986	153	-	-	-	-	-	-	-	-	-	-	-	153
1987	163	109	-	-	365	1,020	1,400	1,400	1,400	-	-	-	837
1988	139	128	136	111	-	-	-	-	-	-	-	-	129
1989	-	-	-	110	-	-	-	-	-	-	-	-	110
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	142	1,400	1,056	-	-	866
1996	139	126	102	112	-	-	1,250	222	177	433	-	-	320
1997	184	145	137	104	-	-	-	-	-	974	-	-	309
1998	397	650	951	869	839	1,010	230	-	416	597	-	-	662
1999	331	135	143	144	131	-	1,400	1,400	955	1,400	-	-	671
2000	249	198	156	363	510	-	-	-	171	-	-	-	274
2001	186	109	-	105	-	-	-	146	-	-	-	-	137
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	65	53	54	64	61	68	149	130	151	149	-	-	162
Max	397	650	951	869	839	1,020	1,400	1,400	1,400	1,400	-	-	866

Sensitivity I
Divertable Flow with 500 cfs Capacity Restrictions
Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	2,511	-	-	213	-	-	990	10,397	-	-	-	-	14,111
1986	2,136	-	-	-	-	-	-	-	992	1,160	1,118	-	5,405
1987	7,661	2,729	-	425	5,825	25,584	21,356	29,581	6,532	-	-	-	99,694
1988	4,280	6,612	3,128	2,888	-	-	-	-	-	-	718	-	17,624
1989	200	-	-	438	-	-	-	-	-	-	-	-	638
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,639	29,753	4,623	-	-	36,015
1996	3,362	1,790	202	1,276	222	-	3,850	1,943	931	2,245	-	-	15,819
1997	8,784	8,330	6,432	409	-	-	-	-	-	11,143	-	-	35,098
1998	17,384	20,511	30,549	22,348	22,175	14,509	798	-	1,267	4,378	-	-	133,920
1999	11,098	4,018	5,298	2,143	2,924	-	29,590	29,753	5,176	12,587	-	-	102,587
2000	11,411	9,116	3,459	12,045	19,094	-	-	-	833	-	-	-	55,958
2001	6,750	2,702	-	615	200	-	-	290	-	-	-	-	10,556
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	5,984	-	-	-	-	-	-	-	5,984
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	2,519	1,860	1,636	1,427	1,881	1,336	1,886	2,453	1,516	1,205	61	-	17,780
Max	17,384	20,511	30,549	22,348	22,175	25,584	29,590	29,753	29,753	12,587	1,118	-	133,920

Sensitivity II (a)
Divertible Flow with 200 cfs Winter Bypass and No Capacity Restrictions

Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	131	-	-	14	-	-	990	11,076	-	66	-	-	12,277
1986	350	-	-	-	-	-	-	-	1,262	1,280	1,118	-	4,010
1987	1,711	151	-	29	3,604	33,028	70,850	88,064	10,632	-	-	-	208,069
1988	1,932	860	549	111	-	-	42	56	-	-	901	-	4,450
1989	2	-	-	41	-	-	-	-	-	-	-	-	43
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,955	73,423	7,631	-	-	83,009
1996	387	203	3	86	23	-	5,802	2,046	1,230	3,142	67	-	12,989
1997	2,833	2,182	1,077	12	-	-	-	-	-	16,721	-	-	22,824
1998	11,433	17,266	43,738	19,925	24,169	21,526	919	-	1,429	4,813	-	-	145,218
1999	5,148	646	537	358	346	-	102,199	91,870	7,637	19,347	-	-	228,087
2000	5,460	2,968	880	6,888	12,984	-	57	-	1,146	-	-	-	30,384
2001	1,196	123	-	89	2	-	143	351	-	-	-	-	1,904
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	1,291	-	-	-	-	-	-	-	1,291
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	1,019	813	1,559	918	1,414	1,818	6,033	6,514	3,225	1,767	70	-	25,152
Max	11,433	17,266	43,738	19,925	24,169	33,028	102,199	91,870	73,423	19,347	1,118	-	228,087

Sensitivity II (b)
Divertable Flow with 200 cfs Winter Bypass and 700 cfs Capacity Restrictions
Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	990	10,779	-	-	-	-	11,769
1986	-	-	-	-	-	-	-	-	1,202	1,160	1,118	-	3,480
1987	-	-	-	-	3,466	31,001	29,467	40,836	7,878	-	-	-	112,648
1988	-	-	-	-	-	-	-	-	-	-	718	-	718
1989	-	-	-	-	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	1,722	41,613	5,860	-	-	49,195
1996	-	-	-	-	-	-	4,711	1,943	931	2,245	-	-	9,829
1997	-	-	-	-	-	-	-	-	-	13,169	-	-	13,169
1998	11,433	16,881	40,546	19,572	21,726	18,067	798	-	1,267	4,656	-	-	134,946
1999	3,728	-	-	-	-	-	40,849	41,208	6,413	14,831	-	-	107,029
2000	3,320	-	-	5,392	12,808	-	-	-	833	-	-	-	22,354
2001	-	-	-	-	-	-	-	290	-	-	-	-	290
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	616	563	1,352	832	1,267	1,636	2,561	3,226	2,005	1,397	61	-	15,514
Max	11,433	16,881	40,546	19,572	21,726	31,001	40,849	41,208	41,613	14,831	1,118	-	134,946

Sensitivity III (a)
Divertible Flow with 400 cfs Summer Bypass and No Capacity Restrictions
Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	485	349	211	-	-	-	-	-	-	-	1,045
1984	458	1,819	1,093	1,531	1,029	-	-	-	-	-	-	-	5,929
1985	5,520	4,372	2,173	3,084	2,098	-	1,197	12,416	-	66	-	-	30,925
1986	5,487	4,190	2,648	3,372	1,802	-	5	206	1,659	2,004	1,810	-	23,182
1987	7,661	5,983	5,130	4,847	8,834	38,217	74,381	91,144	12,652	-	18	27	248,895
1988	5,387	7,006	5,496	5,568	4,048	-	42	278	-	-	1,594	-	29,418
1989	4,192	5,258	3,440	2,682	1,315	-	185	-	87	-	-	-	17,159
1990	51	1,054	2,010	1,607	1,733	-	-	-	-	-	-	-	6,454
1991	80	153	844	451	-	-	-	-	-	-	-	-	1,528
1992	-	-	10	144	-	-	-	-	-	-	-	-	154
1993	-	132	532	1,800	2,307	-	-	-	-	-	-	-	4,771
1994	1,968	2,770	2,974	2,314	299	-	-	-	-	-	-	-	10,326
1995	1,318	2,886	2,941	1,694	1,571	-	185	2,715	74,018	9,111	-	-	96,439
1996	5,915	5,600	5,052	3,132	2,695	-	6,199	3,778	2,029	5,755	1,056	-	41,211
1997	8,784	8,330	7,219	4,246	2,942	25	87	42	-	20,207	681	28	52,591
1998	17,384	22,528	49,887	25,479	30,318	26,130	1,790	-	1,794	6,480	-	-	181,789
1999	11,098	6,609	5,488	5,513	6,060	-	106,774	96,580	9,025	21,833	12	-	268,993
2000	11,411	9,116	5,573	12,560	19,133	-	589	-	2,241	-	-	-	60,624
2001	7,145	5,875	5,276	2,686	4,538	-	772	883	-	-	-	-	27,174
2002	349	1,743	1,327	1,319	623	-	-	-	69	-	-	-	5,431
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	286	20	-	1,400	7,109	-	-	-	-	-	-	-	8,815
2008	14	567	813	290	30	-	-	-	-	-	-	-	1,714
2009	781	752	161	22	-	-	-	-	-	-	-	-	1,716
2010	2,696	1,692	1,801	1,472	1,886	-	-	-	-	-	-	-	9,547
2011	-	-	118	135	-	-	-	-	-	-	-	-	253
Mean	3,266	3,282	3,750	2,923	3,353	2,146	6,407	6,935	3,452	2,182	172	2	37,869
Max	17,384	22,528	49,887	25,479	30,318	38,217	106,774	96,580	74,018	21,833	1,810	28	268,993

Sensitivity III (b)
Divertable Flow with 400 cfs Summer Bypass and 700 cfs Capacity Restrictions
Acre-Feet

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1982	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	2,511	-	-	213	-	-	1,188	12,245	-	-	-	-	16,158
1986	2,136	-	-	-	-	-	-	-	1,646	1,676	1,713	-	7,171
1987	7,661	2,729	-	425	6,183	34,343	29,467	41,111	9,410	-	-	-	131,329
1988	4,280	6,612	3,128	2,888	-	-	-	254	-	-	1,496	-	18,657
1989	200	-	-	438	-	-	-	-	-	-	-	-	638
1990	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	2,479	41,654	6,709	-	-	50,841
1996	3,362	1,790	202	1,276	222	-	5,078	3,236	2,029	4,386	265	-	21,845
1997	8,784	8,330	6,432	409	-	-	-	-	-	15,125	-	-	39,080
1998	17,384	22,514	42,114	24,509	26,311	20,427	1,514	-	1,603	6,003	-	-	162,380
1999	11,098	4,018	5,298	2,143	2,924	-	41,287	41,325	7,206	17,006	-	-	132,305
2000	11,411	9,116	3,459	12,045	19,133	-	454	-	2,138	-	-	-	57,756
2001	6,750	2,702	-	615	200	-	738	748	-	-	-	-	11,752
2002	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	5,984	-	-	-	-	-	-	-	5,984
2008	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-
Mean	2,519	1,927	2,021	1,499	2,032	1,826	2,658	3,380	2,190	1,697	116	-	21,863
Max	17,384	22,514	42,114	24,509	26,311	34,343	41,287	41,325	41,654	17,006	1,713	-	162,380