GARY R. HERBERT
Governor
SPENCER J. COX

State of Utah

DEPARTMENT OF NATURAL RESOURCES
MICHAEL R. STYLER
Executive Director
Division of Water Rights
KENT L. JONES
State Engineer/Division Director

Subj: Annual Recharge Estimate for Cedar City Valley

From: David Jones, P.E.

Date: November 23, 2016

Executive Summary

Several estimates of annual recharge in Cedar City Valley were reviewed or constructed. These include estimates from a USGS flow budget study, a groundwater model, a chloride mass balance calculation, a BCM method, and a storage change method. These recharge estimates range from 21,000 to 32,000 acre-feet per year. The best available data suggests the average annual recharge is 21,000 acre-feet.

The large variation is primarily due to an improved understanding of the amount of valley precipitation that recharges the aquifer – the flow budget estimate supposed that valley precipitation seepage was over 10,000 acre-feet, while newer estimates suggest it is near zero.

Average annual depletion from groundwater pumping has been about 28,000 acre-feet per year over the past 15 years. The aquifer is being over-pumped by about 7,600 acre-feet, which is 27% of the actual pumping depletions.

1594 West North Temple, Suite 220, PO Box 146300, Salt Lake City, UT 84114-6300
telephone (801) 538-7240 • facsimile (801) 538-7467 • TTY (801) 538-7458 • *www.waterrights.utah.gov*

Annual Recharge Estimate for Cedar City Valley

Date: Nov 23, 2016

Utah statute defines three objectives of a groundwater management plan. The first objective is to "limit groundwater withdrawals to safe yield"[1]. Safe Yield depends on several considerations, one of which is the "long-term recharge of the basin"[2]. This paper summarizes existing estimates of recharge in Cedar City Valley (Cedar Valley) and an analysis completed by Division staff of the average amount of recharge to this basin's groundwater system.

Several published studies provide information about the quantity of recharge to Cedar Valley. USGS Scientific Investigations Report 2005-5170 describes three estimates of annual recharge to the valley-fill aquifer: (1) a *water budget estimate* (involving a Maxey-Eakin regression equation), (2) a *groundwater model estimate*, and (3) a *chloride mass-balance estimate*.[3] USGS Scientific Investigations Report 2010-5193 introduced an improved method for estimating recharge from precipitation seepage for areas within the Great Basin.[4] Using datasets from this study, we determined a (4) *BCM estimate* of recharge. Finally, we independently obtained a (5) *storage change estimate*, using measured groundwater level declines and water use data with the principal that inflows plus storage consumption must balance outflows.

The following sections describe these five estimates in greater detail. Some adjustments were made to published figures to express annual recharge consistently and in the most appropriate manner. For example, the USGS water budget includes *return-recharge* components like seepage from excess irrigation – the irrigation water was pumped from the aquifer and a portion was allowed to return. *Return-recharge* like this is not new water entering the basin. Unless otherwise stated, estimates in this paper do not include return-recharge components and outflows are expressed as depletions.

---

[1] Utah Code 73-5-15 (2)(b)
[2] Utah Code 73-5-15 (1)(b)
[3] Lynette E. Brooks and James L. Mason, "Hydrology and Simulation of Ground-Water Flow in Cedar Valley, Iron County, Utah," U.S. Geological Survey. Scientific Investigations Report 2005-5170 (2005).
[4] Victor M. Heilweil, and Lynette E. Brooks, editors, "Conceptual Model of the Great Basin Carbonate and Alluvial Aquifer System" U.S. Geological Survey. Scientific Investigations Report 2010-5193 (2011).

Water budget estimate of annual recharge

USGS estimated the amount of recharge from stream seepage, irrigation seepage, seepage from precipitation on the basin-fill, inflow from precipitation that infiltrates the bedrock above the valley then flows underground to the valley aquifer, and a few other inflows. The components of the water budget are listed in Table 1. Approximately 10,000 acre-feet of this total appears to be return-recharge. Return-recharge includes the entire amount of seepage from groundwater irrigation and, inasmuch as the municipal water is diverted from underground sources, seepage from waste-water effluent and from lawn and garden watering. The amount of municipal water seeping into the aquifer that originates from non-underground sources is thought to be negligible in comparison to the uncertainty of other budget components such as precipitation recharge.

Table 1. Water Budget Estimate for Cedar Valley for the Year 2000

Component	**Counting Return-Recharge** ***acre-feet***	**Not Counting Return-Recharge** ***acre-feet***
Recharge – Total	**41,000 - 43,000**	**32,000**
Seepage from groundwater irrigation	7,100-8,600	0
Seepage from surface irrigation	4,900	4,900
Seepage from waste-water effluent	1,500	negligible
Seepage from lawn and garden watering	600 - 1,000	negligible
Precipitation on basin-fill	10,300	10,300
Precipitation on mountain areas	9,900	9,900
Seepage from streams and canals	4,700 - 5,100	4,700 - 5,100
Subsurface inflow from Parowan Valley	2,000	2,000
Discharge – Total	**40,000**	**30,000**
Wells[5]	36,000	26,000
Evapotranspiration	3,000	3,000
Subsurface outflow	1,000	1,000
Springs	0	0

[5] The USGS study area may not have been exactly the same as water right Area 73. The 36,000 acre-feet of withdrawals may include about 1,800 acre-feet of wells located in Kanarraville. This is inferred from a comparison of the well withdrawals in the budget to well withdrawals in the groundwater flow model and the note below the caption for table 15 in SIR 2005-5170.

Well depletion, the portion of well withdrawals that do not return to the aquifer, was calculated by reducing well withdrawals by seepage from groundwater irrigation, waste-water effluent, and from lawn and garden watering.

Citing the downward trend of groundwater levels, USGS noted that recharge cannot actually be exceeding discharge and might be overestimated by this budget.[6] A reason for this discrepancy may be the large recharge component for precipitation on basin-fill. As discussed later, more recent studies suggest little if any precipitation on basin-fill recharges the aquifer.

Groundwater model estimate of annual recharge

The groundwater flow model developed by the USGS provides a refined estimate of the annual recharge since the amounts of inflow and outflow were adjusted so simulated water levels would match measured water levels. This model calibration required notable decreases to the recharge rates estimated by the budget, particularly the precipitation on basin-fill and precipitation on bedrock components. USGS produced a steady state model, a transient model, and several projection models.[7]

The steady state model simulates conditions during the 1940's which are not representative of current conditions. The transient model has been used to estimate inflows, outflows, and change in storage for individual years,[8] but these annual estimates are not necessarily representative of long-term average conditions. The model variant that is best suited to provide a recharge estimate that is both current and representative of average conditions is projection model #1. Projection #1 simulated how groundwater levels would change from 2000 onward if well withdrawals stayed the same as they were in 2000 and recharge each year was average.

---

[6] SIR-5170, p. 30

[7] The input and output files for these models are available online: http://www.waterrights.utah.gov/groundwater/gwmodelsview.asp

[8] For example, a recent report by Utah Geologic Survey cited the transient model budget for year-2000. They noted that groundwater outflow exceeded recharge in this year by 9,100 acre-feet. (Knudsen and others, 2014, "Investigation of land subsidence and earth fissures in Cedar Valley, Iron County, Utah," Utah Geological Survey. Special Study 150. See pages 13-14). But this year is not ideal for an estimate of average long term recharge because simulated recharge in 2000 was less than average.

Simulated recharge and discharge amounts were obtained for the 2001 to 2015 water years from projection #1. The total average annual recharge was 27,100 acre-feet per year. Since actual well pumping has increased since 2000, the simulation result for well pumping was replaced with the actual well pumping during this period, and this additional water was assumed to come from storage. The water budget shown in Table 2 reflects these adjustments. Actual pumping from 2000 to 2014 exceeded long-term recharge by about 7,700 acre-feet per year.

Table 2. Projection #1 Model Water Budget Estimate for Cedar Valley, from 2001 to 2015

Component	***Flow acre-feet***
Recharge – Total	**27,100**
Surface water irrigation return flow and seepage from streams and canals[9]	14,300
Precipitation on basin-fill	5,900
Precipitation on mountain areas	4,100
Inflow from Parowan Valley	2,500
Inflow from Kanarraville area	200
Discharge – Total	**34,800**
Wells[10]	27,800
Evapotranspiration	3,400
Subsurface outflow	2,500
Springs	1,100
Removal from storage	**7,700**

We consider the model estimate of total annual recharge to be an improvement from the conceptual budget estimate total, but have some concerns with the model's estimates of individual components. USGS reported that spring discharge in the Enoch area no longer exists and only shows up in the model due to "a known error in the model calibration."[11] Since most of

[9] This recharge component was reduced by 10,000 acre-feet of return-recharge.
[10] Well withdrawals were simulated using year-2000 rates, or 34,200 acre-feet. Actual well consumption for 2000 to 2014 is thought to average 27,800 acre-feet, as computed for the storage change estimate which is described later.
[11] SIR-5170, p. 105. The model computes spring discharge near Enoch when the simulated water level is above land surface. In the 1940's, water levels were high and springs were observed. Since that time, water levels have declined

the simulated evapotranspiration also occurs near Enoch, it is possible that the model estimate of evapotranspiration is also too high due to the model underestimating the depth to water in this area. Subsurface outflow could similarly be overestimated. If these natural discharges are overestimated by the model, average recharge may also have been overestimated in order to match observed water levels in the calibrated simulations.

Chloride mass-balance estimate of annual recharge

USGS also estimated the long-term average annual recharge using a chloride mass-balance approach. This method involved measuring chloride concentrations in the aquifer, in precipitation samples, and in Coal Creek. Then the average total recharge to the aquifer ($Q_{aquifer}$) was calculated with the following equation:[12]

$$Q_{aquifer} = \frac{Q_{Precip}Cl_{Precip} + Q_{Coal\ Creek}Cl_{Coal\ Creek}}{Cl_{aquifer}}$$

The result of this calculation was 18,800 acre-feet of recharge from precipitation and Coal Creek seepage. Seepage from irrigation with surface water is included with Coal Creek seepage.[13] If there is an additional 2,000 acre-feet of subsurface inflow from Parowan Valley, the total average recharge would be 20,800 acre-feet per year.

This mass-balance estimate was based on limited sampling data and "should be considered a rough approximation".[14]

BCM estimate of recharge from precipitation

USGS recently used the Basin Characterization Model (BCM) to estimate precipitation recharge throughout the Great Basin, including Cedar Valley. The BCM divides the area into a grid of 18-acre cells and then tracks snowfall, snowmelt, rainfall, evapotranspiration, soil water storage,

---

and springs have ceased flowing. Because the model is not able to exactly simulate the decline in water levels in the Enoch area, it is not able to simulate the correct decrease in spring discharge.

[12] SIR-5170, pp. 52-54

[13] SIR-5170, p. 54

[14] SIR-5170, p. 54

surface runoff, and aquifer recharge within each cell at monthly time steps. Water that enters a grid cell through precipitation or snowmelt is first made available to ET. Remaining water then goes to fill soil storage and possibly becomes aquifer recharge. A maximum recharge rate is defined with a hydraulic conductivity parameter, and surface runoff occurs if more water is available than can be recharge at this maximum rate. The model was calibrated by adjusting hydraulic conductivity values to get the runoff results to match measured stream flows throughout the Great Basin. Resulting spatially-distributed recharge and runoff datasets were used to generate recharge estimates for basins within the Great Basin study area.[15]

The spatially-distributed recharge dataset was obtained and cropped to the area where recharge from precipitation is thought to flow toward the basin-fill aquifer (see Figure A2). In most areas, groundwater is anticipated to flow in the same direction as surface water and the recharge dataset was cropped to topographic boundaries surrounding the basin. The upper Coal Creek drainage is one area that is an exception. As indicated by Table 3 and Figure 6 (pp. 20-21) of SIR 2005-5170, no significant amounts of mountain recharge in the upper Coal Creek drainage are believed to reach the valley aquifer. Much of the recharge in this area discharges as Coal Creek base flow, and deep underground flow paths would likely flow towards the east along eastward dipping bedrock units. Using the spatially-distributed recharge dataset, average annual in-place recharge in the remaining areas of Cedar Valley outside of the upper Coal Creek drainage is 8,800 acre-feet.

The BCM estimates no recharge from precipitation in valley areas. In valley areas, potential ET and soil storage are large enough to consume or retain any precipitation.

Stream seepage to the valley aquifer was also estimated as part of the study that involved the BCM calculations. For basins like Cedar Valley where surface water is highly utilized for irrigation, stream seepage was combined with canal seepage and surface water irrigation return seepage, and was estimated to be 30 percent of the total stream flow. Using this study’s figures, the average recharge from seepage from streamflow and surface irrigation in Cedar Valley is

[15] Heilweil, V.M., and Brooks, L.E., eds., 2011, Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010-5193, 191 p. Appendix 3 describes the BCM. Appendix 6 indicates how to obtain the resulting in-place recharge spatial dataset.

10,100 acre-feet.[16] Since this estimate is based on a generalized assumption for multiple basins, it should not necessarily be considered an improvement on the previous flow budget estimate that was the result of a more localized study.

The BCM method does not provide an estimate for subsurface inflow. If subsurface inflow from Parowan Valley is assumed to be 2,000 acre-feet as suggested by the flow budget, then the total recharge can be summed to 20,900 acre-feet as outlined in Table 3.

Table 3. BCM Recharge Estimates for Cedar Valley

Component	***Flow acre-feet***
Recharge – Total	**20,900**
Precipitation on mountain areas	8,800
Precipitation on basin-fill	0
Seepage from surface water irrigation and seepage from streams and canals	10,100
Subsurface inflow from Parowan Valley (Taken from flow budget; this component was not estimated by the BCM)	2,000

[16] SIR 2010-5193, See Appendix 4 and Auxiliary 3A. 10,100 acre-feet is the sum of 2,000 acre-feet of seepage from mountain stream base flow and 8,100 acre-feet of seepage from runoff. SIR 2010-5193 reported BCM recharge and runoff estimates that had been increased by a factor of 1.37 in Cedar Valley in order to more closely match the total recharge estimate reported in previous SIR 2005-5170 (see p. 20 of SIR 2010-5193 Chapter D). The un-factored results are used here because we question the accuracy of the earlier estimate, we already presented the results from the earlier study, and because we wish to compare each recharge estimate independently.

Storage change estimate of annual recharge

An additional estimate of recharge can be made by analyzing the change in water levels in wells. When groundwater is withdrawn at a greater rate than it is recharged, the amount of water stored within the aquifer is reduced by the amount that discharge exceeds recharge:

$$\Delta_{StorageLoss} = Q_{Outflow} - Q_{Recharge}$$

The amount of this storage reduction is also directly related to the decline in water levels. By estimating the storage loss from water level data, and with an estimate of outflows, the recharge can be calculated.

Data from 2000 to 2015 was used for this calculation. The flow of Coal Creek during this period appears to be close to the long-term average, though precipitation at the airport was 0.4 inches above the 1949 to 2014 average.[17] This period is subsequent to the USGS study, allowing the calculation to represent more recent conditions. This period also allows storage change to be estimated using beginning water level measurements made at the same wells as the ending measurements. Water level measurements were made during March 2000 and March 2015 at 24 wells. Water levels were estimated at the two additional locations where annual data collection began shortly after 2000 up to 2015.[18]

The change in aquifer storage equals the change in water level multiplied by specific yield. Polygons were constructed around the water level data points within the approximate bounds of the valley fill aquifer. For each polygon, the change in storage was calculated by multiplying the change in water level by the specific yield used in the USGS groundwater flow model and by the polygon area. The resulting loss in storage summed to 115,000 acre-feet, or about 7,600 acre-feet annually.[19]

---

[17] Burden, C.B., and others, Ground-water conditions in Utah, spring of 2015

[18] Projected water levels during 2000 for wells (C-33-11)31aad-2 and (C-35-11)14bac-2 were 39 and 22 feet below ground surface, respectively.

[19] The results of similar analyses have been reported for different time periods. Technical Publication 60 (p. 39) estimated the loss in storage from 1940 to 1974 averaged 3,300 acre-feet per year. UGS Special Study 150 (p. 13) similarly estimated that the loss in storage in 2000 was 10,700 acre-feet. Both these estimates used a specific yield of 0.1.

As outlined in Table 4, the total outflow from well depletion and any natural outflows sums to 28,800 to 31,800 acre-feet per year:

Table 4. Summary of Depletion Sources and Other Aquifer Outflows

Groundwater Depletion	**Acre-Feet**
Irrigation with groundwater (28,400 acre-feet of depletion from surface and groundwater sources, minus 7,400 acre-feet of depletion from surface sources)	21,000
Municipal well diversion (7,200 acre-feet of well withdrawals, minus 670 acre-feet of lawn/garden return seepage, minus 250 acre-feet of treated effluent return seepage)	6,300
Industrial wells	90
Domestic and stock wells	400
Evapotranspiration (ET)	0 – 3,000
Subsurface outflow through Mud Springs Gap	1,000
Total Depletion	**28,800 – 31,800**

- ***Irrigation with ground and surface water:***

  Water related land use surveys, conducted by the Division of Water Resources in Cedar Valley for the years 2013, 2007 and 2001, indicate crop type and acreage of irrigated land.[20] Average watering needs of an acre of various crop types have been estimated for the valley.[21] An estimate of water consumed by irrigation of a particular crop type can be made by multiplying the crop acreage by its water requirement per acre. For the three years which were surveyed, the total irrigation consumption for all crops averaged 28,400 acre-feet.

  This irrigation consumption is provided by both groundwater and surface sources; to get the groundwater depletion, the contribution from surface sources must be subtracted out.

[20] Data available at http://gis.utah.gov/data/planning/water-related-land/

[21] Hill, Robert W., "Consumptive Use of Irrigated Crops in Utah," Utah Agricultural Experiment Station, Research Report 145 (1998), p. 160, 161

If all available surface water was diverted for irrigation, surface water consumption would include 125 acre-feet from Shirts Creek[22] and 54 percent[23] of the flow in Coal Creek from April 1 through September 30; using this method, the surface water consumption for the three years would average 7,400 acre-feet. The remaining irrigation consumption provided by groundwater is 21,000 acre-feet.

- ***Municipal well depletion:***

  Groundwater withdrawals for public supply averaged 7,200 acre-feet from 2000 to 2014. After reducing this amount by unconsumed lawn/garden and effluent seepage, the resulting municipal well depletion total is 6,300 acre-feet.

  Municipal lawn/garden return-seepage:

  USGS estimated 600 to 1,000 acre-feet of recharge from irrigation of lawns and gardens with municipal water. They estimated outside watering by analyzing the summer increase in municipal use, and assumed a seepage rate of 15 to 25 percent[24]. Data reported by the public water suppliers in Cedar Valley show that 84 percent of municipal water is pumped from wells rather than diverted from springs,[25] so return-seepage is 84 percent of total seepage. If 800 acre-feet of all municipal water seeps into the aquifer after being applied on lawns and gardens, the return-seepage from wells would be 670 acre-feet.

  Municipal treated effluent return-seepage:

  Effluent from the Cedar City Regional Wastewater Treatment Facility is used to irrigate neighboring land. For 2000, USGS estimated 1,500 acre-feet of seepage from land application of waste-water effluent. They assumed 50 percent of the applied effluent seeps into the aquifer in the summer and 80 percent in the winter. Again, with 84 percent of municipal water originating from wells, the return seepage from waste-water effluent

[22] SIR-5170, p. 16. Flows in Shirts Creek were estimated to be 325 acre-feet in 2000, and recharge from Shirts Creek was estimated to be 200 acre-feet. The remaining 125 acre-feet would be consumed by irrigation.
[23] 90 percent of Coal Creek flows may be available for irrigation after seepage losses (10 percent seepage losses, SIR-5170, p. 16), then 60 percent of the applied irrigation does not seep back into the aquifer but rather is consumed (40 percent seepage return flows, SIR-5170, p. 18). 0.9 x 0.6 = 0.54.
[24] SIR-5170, p. 18
[25] Water use data is available online from the Division of Water Rights website. For comparison, see Cedar City 2015 Water Report, p. 5.

would be 1,260 acre-feet. Satellite images indicate vegetation increased notably from 2000 to about 2006 in an area north of the principle 640 acres irrigated by effluent (See figure A1). The USGS estimate may be for years when effluent is only consumed on these 640 acres. The increase appears to be more consistent with a report that indicates effluent may be spread over 2,300 acres of pasture during the winter.[26] Based on an approximate relationship[27] between enhanced vegetation index (EVI) and evapotranspiration, it is possible that the effluent has been fully consumed by the increased vegetation. If in 2000 there was 1,260 acre-feet of unconsumed return-recharge, and if this decreased linearly to no return-recharge in 2006, then the average return-recharge from the treated effluent for the 15 year period would be 250 acre-feet per year.

- ***Industrial:***

  Groundwater withdrawals for industrial use have averaged 90 acre-feet from 2000 to 2014. This same quantity is thought to be depleted.

- ***Domestic and stock:***

  Groundwater withdrawals for both domestic use and stock watering have averaged 2,000 acre-feet from 2000 to 2014. About 20 percent, or 400 acre-feet, is thought to be depleted.

- ***Subsurface outflow and evapotranspiration:***

  USGS estimated 1,000 acre-feet left Cedar Valley through Mud Springs Canyon based on a Darcy's law calculation. USGS estimated another 3,000 acre-feet was lost through evapotranspiration in 2000; this estimate was obtained after mapping 6,000 acres of riparian and phreatophyte vegetation and using an evapotranspiration rate of 0.5 feet per year (this rate was extrapolated from a chart relating evapotranspiration rate to water table depth in the Great Basin). For this analysis, evapotranspiration in riparian areas should not be counted as groundwater consumption, but there is no information with the

[26] "Water Reuse in Utah", Division of Water Resources (2005)

[27] Beamer and others. "Estimating annual groundwater evapotranspiration from phreatophytes in the Great Basin using Landsat and flux tower measurements." Journal of the American Water Resources Association. Vol. 49, No. 3 (2013).

USGS estimate to separate riparian and phreatophyte evapotranspiration.

A vegetation index image for year-2000 shows only a few small areas near Rush Lake as having greater than normal vegetation cover. Aside from this location, vegetation index appears to correlate better with surface runoff ravines rather than locations of shallow groundwater. Images for subsequent years are dominated by vegetation which is presumably fed by effluent from the municipal wastewater treatment plant, as mentioned and accounted for earlier. Yet, the extent of shallow groundwater is large enough – larger than the 6,000 acres mapped by USGS – that the possibility of 3,000 acre-feet of evapotranspiration cannot be ruled out. For this analysis, evapotranspiration is thought to be between 0 and 3,000 acre-feet.

Using the estimate of total depletion and of change in storage, annual recharge can be calculated:

$$\Delta_{StorageLoss} = Q_{Outflow} - Q_{Recharge}$$

$$Q_{Recharge} = Q_{Outflow} - \Delta_{StorageLoss}$$

$$Q_{Recharge} = (28{,}800\ to\ 31{,}800\ ac\text{-}ft) - (7{,}600\ ac\text{-}ft)$$

$$Q_{Recharge} = 21{,}200\ to\ 24{,}200\ ac\text{-}ft$$

Recharge is estimated to have averaged between 21,200 and 24,200 acre-feet per year over this 15 year period.

Interpretation and conclusions

The annual recharge estimates from each of the 5 methods are summarized in Table 5 below. Table 6 summarizes the same estimates along with a breakdown of each component if estimated. Not every method provides an independent estimate for each component, but the comparison helps identify where the discrepancies occur between the different estimates.

Table 5. Summary of Estimates of Annual Recharge to Cedar Valley Groundwater

Method	**Recharge (*acre-feet*)**
Flow budget	32,000
Groundwater model	27,100
Chloride mass balance	20,800
BCM	20,900
Storage change	21,200 – 24,200

Table 6. Summary of groundwater recharge and discharge component estimates for each method.

Component	**Flow Budget**	**GW Model**	**Chloride Balance**	**BCM**	**Storage Change**
Recharge	**32,000**	**27,100**	**20,800**	**20,900**	**21,200 – 24,200**
Valley precipitation seepage	10,300	5,900	*Sum of 3 components:* 18,800	0	
Mountain precipitation seepage	9,900	4,100		8,800	
Seepage from streams, canals, and surface water irrigation	9,800	14,300		10,100	
Inflow from Parowan	2,000	2,500	2,000	2,000	
Inflow from Kanarraville area	0	200	0	0	
Discharge	**30,000**	**34,800**			**28,800 – 31,800**
Well Depletion	26,000	27,800			27,800
Evapotranspiration	3,000	3,400			0 – 3,000
Subsurface outflow	1,000	2,500			1,000
Spring Discharge	0	1,100			0
Removal from storage	**-2,000**	**7,700**			**7,600**

There is a large variation in estimates of recharge from valley precipitation seepage. USGS explained some of the uncertainties with their estimate of this component in their flow budget:

> "The estimate of 10,300 acre-ft/yr for average recharge from infiltration of precipitation on unconsolidated basin fill, which is based on the Maxey-Eakin method, should be considered a maximum value. The Maxey-Eakin method was developed for mountainous areas and does not account for water storage in soil moisture."[28]

USGS then described studies in other valleys in the Great Basin that had constructed net infiltration models and determined that little or no recharge occurs on valley fill. These models showed that precipitation rarely filled up the soil pore volume deeper than the lowest roots; instead, the precipitation remained near the surface where it was consumed by plants and evaporation. Because of this soil storage, these infiltration models showed that deep seepage into the aquifer was minimal in valley fill arears.[29] Unfortunately, an infiltration model was not available for Cedar Valley at the time the USGS flow budget was developed in the early 2000s.

The BCM estimate of recharge from precipitation seepage is based on a net infiltration model that does account for water storage in soil moisture. For this reason, the BCM estimate of no valley precipitation seepage is considered to be more accurate than the Maxey-Eakin flow budget estimate.

The total annual recharge from the BCM method is estimated to be 21,000 acre-feet. We consider the BCM estimate of precipitation seepage to be the best estimate of this seepage currently available, and the remaining components of this estimate (from Table 6) agree closely or were taken directly from the USGS flow budget estimate. In other words, the total recharge from the flow budget estimate would be about 21,000 acre-feet if the BCM estimates of mountain and valley precipitation seepage were used. This total agrees with the chloride balance estimate and is also comparable to the storage change estimate. We conclude that average annual recharge in Cedar Valley is 21,000 acre-feet.

[28] SIR-5170, p. 19

[29] SIR-5170, p. 19. One of the investigators they cite was Allan Flint, who more recently created the BCM datasets.

There is some variation in estimated well depletion because the flow budget shows well consumption only for year 2000. More recently, average groundwater consumption by water users has been about 28,000 acre-feet per year.

The average annual groundwater water deficit is probably about 7,600 acre-feet, or 27 percent of average pumping depletions.

References

Bjorklund, L.J., Sumsion, C.T., and Sandberg, G.W., 1978, Ground-water resources of the Parowan—Cedar City drainage basins, Iron County, Utah: Utah Department of Natural Resources Technical Publication No. 60, 93 p.

Brooks, L.E., and Mason, J.L., 2005, Hydrology and simulation of ground-water flow in Cedar Valley, Iron County, Utah: U.S. Geological Survey Scientific Investigations Report 2005-5170, 127 p.

Burden, C.B., and others, 2015, Ground-water conditions in Utah, spring of 2015: Utah Department of Natural Resources, Division of Water Resources, Cooperative Investigations Report No. 56, 136 p.

Heilweil, Victor M. and Brooks, Lynette E., editors, 2011, Conceptual Model of the Great Basin Carbonate and Alluvial Aquifer System: U.S. Geological Survey, Scientific Investigations Report 2010-5193.

Hill, Robert W., 1998, Consumptive Use of Irrigated Crops in Utah: Utah Agricultural Experiment Station Research Report 145

Katzenstein, K., 2013, InSAR analysis of ground surface deformation in Cedar Valley, Iron County, Utah: Utah Geological Survey Miscellaneous Publication 13-5, 43 p.

Knudsen, T., Inkenbrandt, P., Lund, W., Lowe, M., and Bowman, S., 2014, Investigation of land subsidence and earth fissures in Cedar Valley, Iron County, Utah: Utah Geological Survey Special Study 150, 116 p.

Thomas, H.E., and Taylor, G.H., 1946, Geology and groundwater resources of Cedar City and Parowan Valleys, Iron County, Utah: U.S. Geological Survey Water Supply Paper 993, 210 p., scale 1:312,500.

Table A1. *Table of Wells Considered, their Change in Water Level, Area of Encompassing Thiessen Polygon, and the Average Specific Yield Used to Estimate Change in Storage*

Well	2000-2015 Change (ft)	Thiessen Polygon Area (ac)	Avg. Specific Yield	Change in Storage (ac-ft)
(C-33-11)31aad- 2	0.0	6,818	0.065	0
(C-34-11) 1daa- 1	-2.4	11,574	0.052	-1,447
(C-34-11) 9cdc- 1	1.7	7,323	0.047	569
(C-34-11)21dcd- 1	2.7	5,320	0.051	729
(C-34-11)23bdd- 1	2.4	4,989	0.041	484
(C-34-11)36dcc- 2	-32.7	5,081	0.059	-9,762
(C-35-11) 4aba- 1	-5.0	6,127	0.053	-1,624
(C-35-11)11ccc- 1	-22.5	1,898	0.044	-1,874
(C-35-11)12dcd- 1	-34.3	2,414	0.070	-5,787
(C-35-11)14bac- 2	-7.6	1,320	0.062	-620
(C-35-11)17dcd- 2	-17.7	6,788	0.066	-7,883
(C-35-11)21dbd- 2	-24.6	1,367	0.040	-1,353
(C-35-11)26acd- 1	-18.3	2,575	0.062	-2,932
(C-35-11)27bbc- 1	-25.0	1,098	0.042	-1,159
(C-35-11)31dbd- 1	-23.1	2,388	0.045	-2,480
(C-35-11)33aac- 1	-26.6	2,992	0.061	-4,886
(C-35-12)36caa- 1	-29.2	4,581	0.042	-5,625
(C-36-11) 8aab- 1	-8.1	2,691	0.070	-1,523
(C-36-12)10aaa- 1	-35.6	4,584	0.040	-6,532
(C-36-12)12dba- 1	-28.9	3,737	0.044	-4,750
(C-36-12)16bba- 1	-45.6	5,308	0.050	-12,008
(C-36-12)32dcc- 1	-50.2	6,796	0.054	-18,450
(C-36-12)35adc- 1	-33.4	6,320	0.040	-8,430
(C-37-12) 9acc- 1	-56.2	3,006	0.058	-9,754
(C-37-12)14abc- 1	-44.5	2,762	0.048	-5,928
(C-37-12)28aac- 1	-24.0	957	0.070	-1,604
Total		**110,816**		**-114,629**

Table A2. *Table Showing Irrigation Depletion Estimate for the Years 2013, 2007 and 2001 for each Crop Type, Based on Water Related Land Use Surveys*

		2013		**2007**		**2001**	
Crop	**Net Irr (in)**	**Irr Area (acres)**	**Depletion (ac-ft)**	**Irr Area (acres)**	**Depletion (ac-ft)**	**Irr Area (acres)**	**Depletion (ac-ft)**
Alfalfa	28.90	9,318	22,440	9,213	22,187	7,273	17,517
Corn	15.10	587	739	287	361	53	66
Grain	18.75	54	84	1,167	1,824	2,389	3,734
Grass Hay	28.90	494	1,189	3	7	670	1,614
Oats	18.75	186	291	0	0	0	0
Pasture	22.39	2,289	4,271	1,612	3,009	2,813	5,249
Turf Farms	19.46	186	302	177	287	22	36
Total			**29,317**		**27,675**		**28,216**

3-Year Average = 28,403 acre-feet

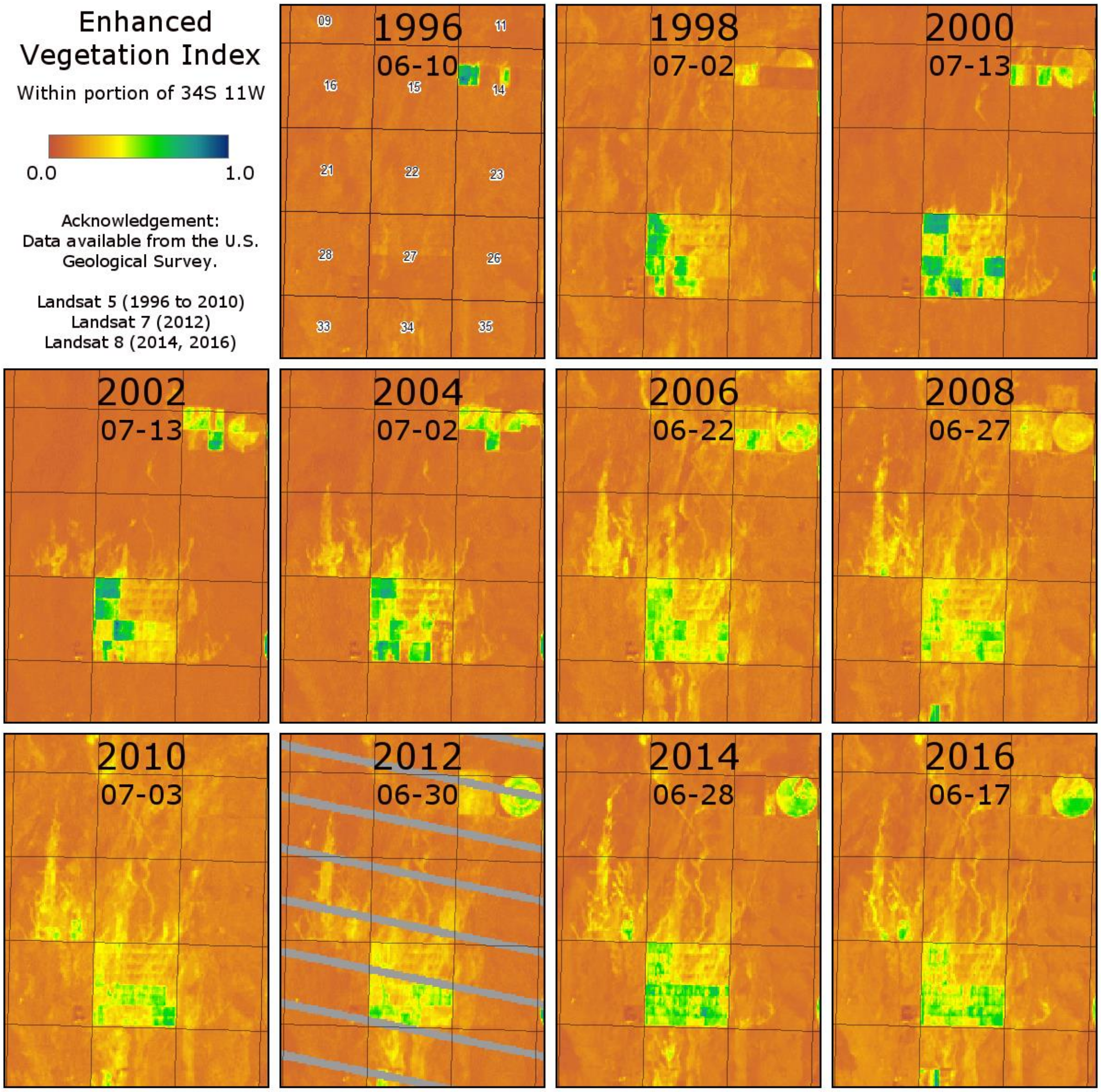

Figure A1. Change in enhanced vegetation index in and surrounding the area where treated effluent is surface-spread.

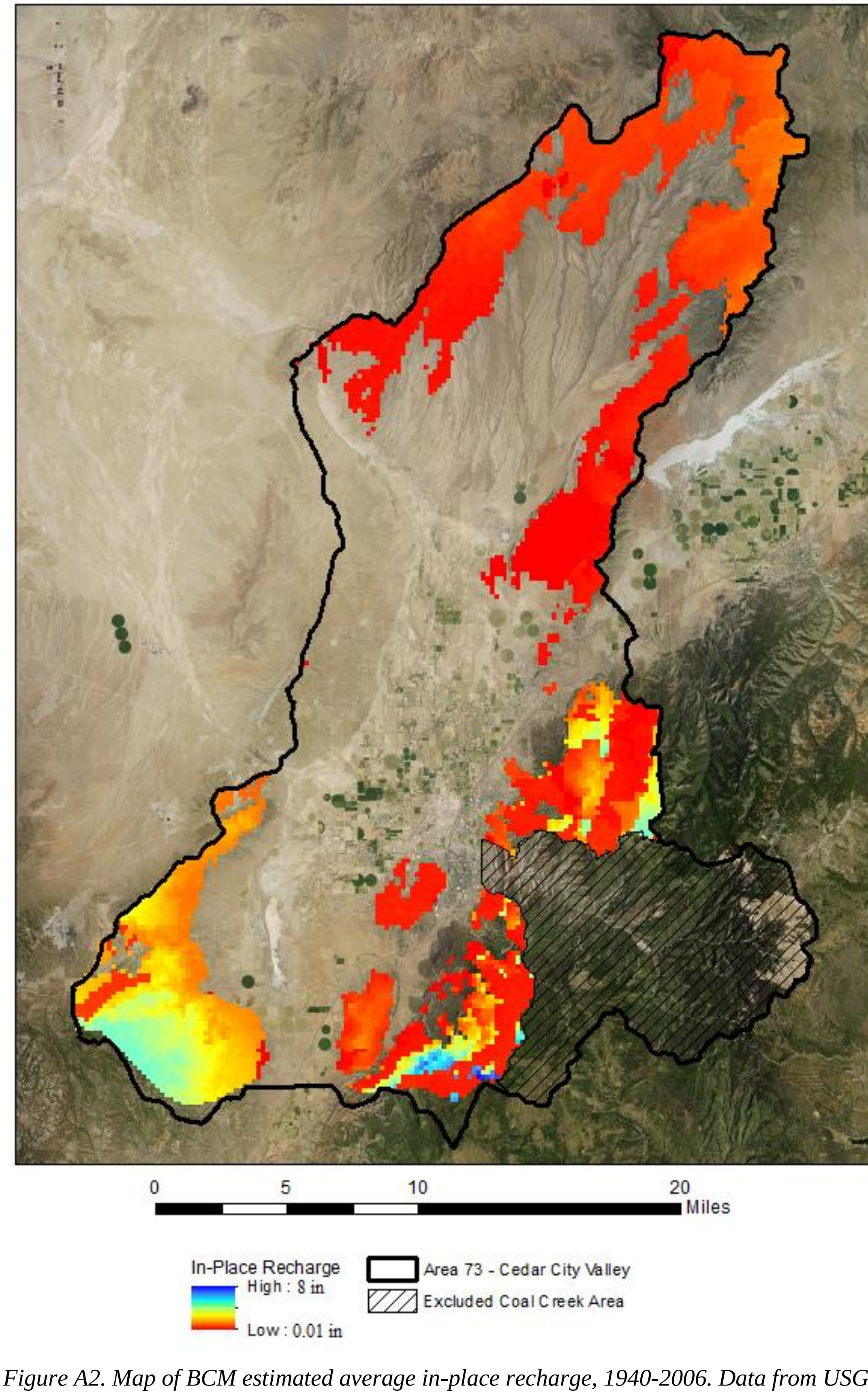

Figure A2. Map of BCM estimated average in-place recharge, 1940-2006. Data from USGS.