

MEMO

To: Jeff Peppersack

From: Mat Weaver 

Date: December 22, 2010

RE: Analysis of METRIC ET and total water supply to develop a methodology for the determination of an annual recharge credit in association with the Fish Creek Aquifer Recharge Plan

Introduction

For several years now the Department has been involved with Brockway Engineering (Brockway) and the Fish Creek Reservoir Company (FCRC) in their on-going effort to develop an aquifer recharge plan in association with the foregone storage lost when the spillway was lowered in 2005. With the lowering of the spillway the storage capacity of Fish Creek reservoir decreased from 14,411 acre-feet to 5,515 acre-feet (a loss of 8,896 acre-feet). Fish Creek Reservoir Company hopes to develop an aquifer recharge use in association with foregone storage, thus providing an alternative use for the lost storage.

The Department met with FCRC and their technical consultant Brockway regarding these matters on January 7, 2010. A summary of the meeting prepared by Brockway can be found in the appendix of this memo. The Department agreed to the following course of action as quoted from the Brockway meeting summary memo.

Bill Kramber will do a METRIC analysis for 2000, 2002, and 2006 to estimate actual ET for the main irrigated area, which will then be compared to actual deliveries to estimate irrigation recharge.

This memo summarizes the Department's efforts in determining METRIC ET and developing an alternative approach to be used in determining a reasonable proportion of the historical storage volume that can now be credited to recharge.

METRIC ET Analysis

Utilizing a shapefile of the Fish Creek Reservoir Company irrigated area¹ (6,991.7 acres) supplied by Brockway, Bill Kramber computed a season total volume of evapotranspiration (ET) associated with the shapefile area for the 1996, 2000, 2002, and 2006 irrigation season. A copy of Bill Kramber's memo regarding his initial analysis can be found in the appendix of this memo. Bill Kramber also developed METRIC ET for a total of 1,043 acres of irrigated lands above the reservoir² for 1996, 2000, and 2006. METRIC ET was not calculated for 2002 due to an insufficient amount of cloud free images. A total volume of ET for all irrigated lands was directly computed for 1996, 2000, and 2006 based on calculated METRIC ET volumes. A volume of ET for 2002 was estimated by assuming the season total ET (per unit area) value developed below the reservoir applies to those lands above the reservoir. Table 1

¹ Only includes irrigated land below the reservoir.

² Refer to the appendix for a graphical depiction of the lands considered by the Department to be irrigated with FCRC water above the reservoir.

summarizes the Department's calculated season-total volumes of water for those years in which METRIC ET is available.

Table 1 - METRIC ET Analysis Summary

Year	Season Total ET* (inches)	Irrigated Area* (acres)	ET* (ac- ft/season)	Season Total ET** (inches)	Irrigated Area** (acres)	ET** (ac- ft/season)	Combined ET (ac- ft/season)
1996	24.0	6,992	13,993	25.0	1,043	2,176	16,169
2000	19.7	6,992	11,492	11.4	1,043	992	12,485
2002	14.9	6,992	8,671	--	1,043	--	9,964
2006	22.2	6,992	12,914	22.8	1,043	1,981	14,896

*Values associated with irrigated area identified by Brockway, only describes irrigated land below reservoir (data not available for 2002).

**Values associated with irrigated area identified by the Department, only describes irrigated land above the re.

Water Balance

The season total volume of ET represents the volume of water lost from the system for all plant ET within the FCRC shapefiles. The volume of water lost due to ET was supplied by three sources: precipitation, surface water diversion (storage and natural flow), and groundwater diversions. A water balance expression for total supply of water available for crop utilization is as follows:

$$(1) \text{ Total Supply} = \text{Precipitation Supply} + \text{Storage Supply} + \text{Natural Flow Supply} + \text{Ground Water Supply}$$

Each component of the total water supply identified in equation (1) is discussed in greater detail in the following sections.

Precipitation Supply

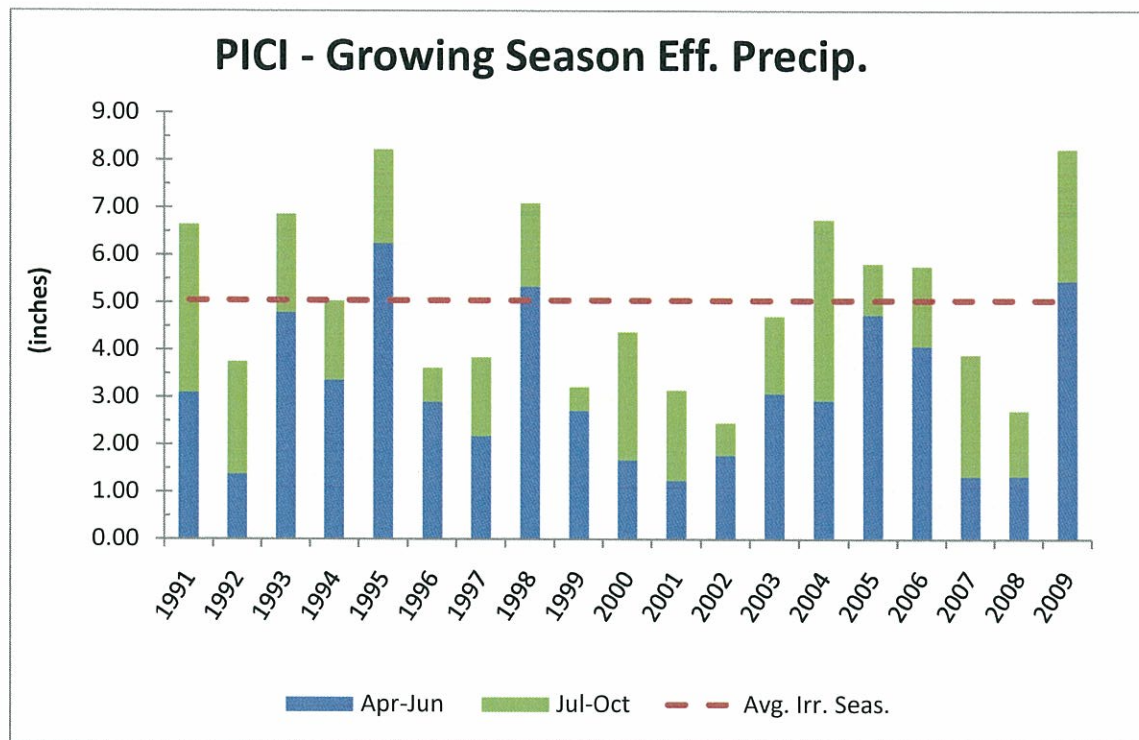
Not all precipitation that occurs in the FCRC boundaries contributes to crop growth and ET. Water that falls outside the growing season is often not available for crop use and only a portion of precipitation occurring in-season is available for crop use. Effective precipitation is defined as the portion of total precipitation that satisfies crop ET requirements. Effective precipitation does not include precipitation that leaves the soil surface as runoff or contributes to subsurface drainage. In considering the contributions of precipitation to crop development in my analysis I have only included in-season (April-October) effective precipitation (W_{eff}).

W_{eff} can be estimated from total precipitation (W) utilizing the methodology presented in the USDA Technical Bulletin 1275³. Total precipitation is provided by the USBR as part of the Pacific Northwest Cooperative Agricultural Network (i.e. AgriMet). Historical precipitation⁴ data for the Picabo, Idaho

³ Harry F. Blaney, 1962. Determining Consumptive Use and Irrigation Water Requirements Technical Bulletin No. 1275, United States Department of Agriculture. Methodology presented on page 13 in Table 3.

⁴ Data obtained from the AgriMet Water Year Report series, which provides access to historical AgriMet archive weather data in a USGS style water report format with 12 monthly columns.
<http://www.usbr.gov/pn/agrimet/yearrpt.html>.

AgriMet station (PICI) was used for analysis. The PICI station is the closest station to the FCRC service area and is at the same elevation. Total precipitation data was considered for the period of 1991-2009. The following figure depicts total effective precipitation for the growing season from 1991-2009.



The data provided in the foregoing figure represents total effective precipitation for the growing season in inches. To convert this data to an annual volume (acre-feet/yer, AFA) the ET value in inches is divided by 12 (to obtain feet) and multiplied by the irrigated area (acres).

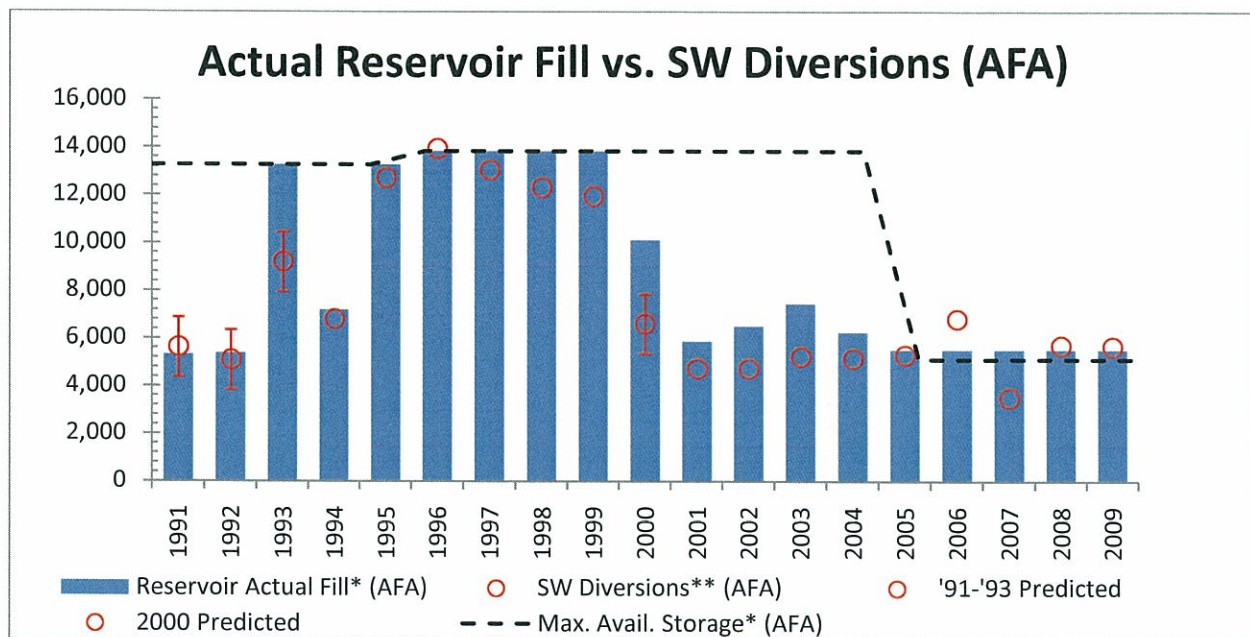
Surface Water Supply

The Watermaster of water district 37-U keeps records⁵ of total diverted surface water by water user for each irrigation season. The Watermaster's records contain diversions both below and above the reservoir. I have compiled a record of annual surface water supply data by reviewing the Watermaster's daily diversions log book and/or annual reports for the years 1994-1999 and 2001-2009. Data for the water years 1991-1993, and 2000 were not available. I have predicted values for the missing years based on a linear regression analysis of surface water diversions for the available years and USGS annual stream flow diversion records for the Little Wood River⁶.

⁵ Records are for water diversion from the stream channel for individual water users, includes some weir measured diversions but predominantly diversions are estimated for wheel lines and pivots by counting sprinkler heads.

⁶ Historical stream flow data for Fish Creek was not found during this investigation. The nearest reliable source of historical stream flow data were two USGS gages located on the Little Wood River. For the purposes of this analysis data from the Little Wood was used as a surrogate for Fish Creek stream flow. Regression analysis was considered for USGS gages #13148500 and #13147900. The stronger correlation was observed when using data for gage #13148500, as such, predictions are based on the regression analysis associated with this gage. The results of the regression analysis are presented in the appendix.

In the records I reviewed prior to 2005, a distinction between storage water and natural flow diversions were not made by the Watermaster. Therefore it was not possible to separate one source from the other. The following figure depicts actual reservoir fill, diverted surface water, and maximum reservoir fill.



In all years prior to the lowering of the spillway, except 1996 (and possibly 1991), total surface water diversions were less than reservoir fill. This suggests that natural flow diversions make up a relatively small proportion of total diverted surface water flow. Further, contributions from natural flow diversions would be at their lowest in dry years, when the reservoir does not fill. Accordingly, it is both necessary and reasonable to treat storage and natural flow diversions as a combined source. I have made no distinction between the two in the evaluation of the water balance and recharge volume.

Ground Water Supply

Within the service area boundary of the FCRC there are five irrigation water rights and one irrigation permit that designate ground water as the source. The following table summarizes pertinent information pertaining to those water rights.

Table 2 - Summary of GW Rights within the FCRC Service Area

WR No.	Owner	Total Acres	Acre Limit	Vol. Limit (AFA)	Supplemental
37-2676*	MILFORD SWEAT	434.4	92.4	1,520.4	No
37-7620*	MILFORD SWEAT	434.4	0.0	1,520.4	Yes
37-2740	P & C IRRIGATION ASSN INC	1,156.0	330.0	1,155.0	Yes
37-7581	ROBERT D WHITBY	460.0	0.0	1,610.0	Yes
37-2578	GARY CARNEY	243.0	0.0	850.5	No
37-8693**	LEON SKELTON	108.0	0.0	--	No

*WRs 37-2676 and 37-7620 have a combined use limitation of 1,520.4 AFA.

**WR 37-8693 is a permit only, proof of beneficial use was filed on June 6, 1994, indicating well was completed in 1991.

The P&C Irrigation Association provides irrigation to four separate members. Table 3 summarizes the pertinent information pertaining to each member of the P&C Irrigation Association.

Table 3 - Summary of PC Irrigation Association Members

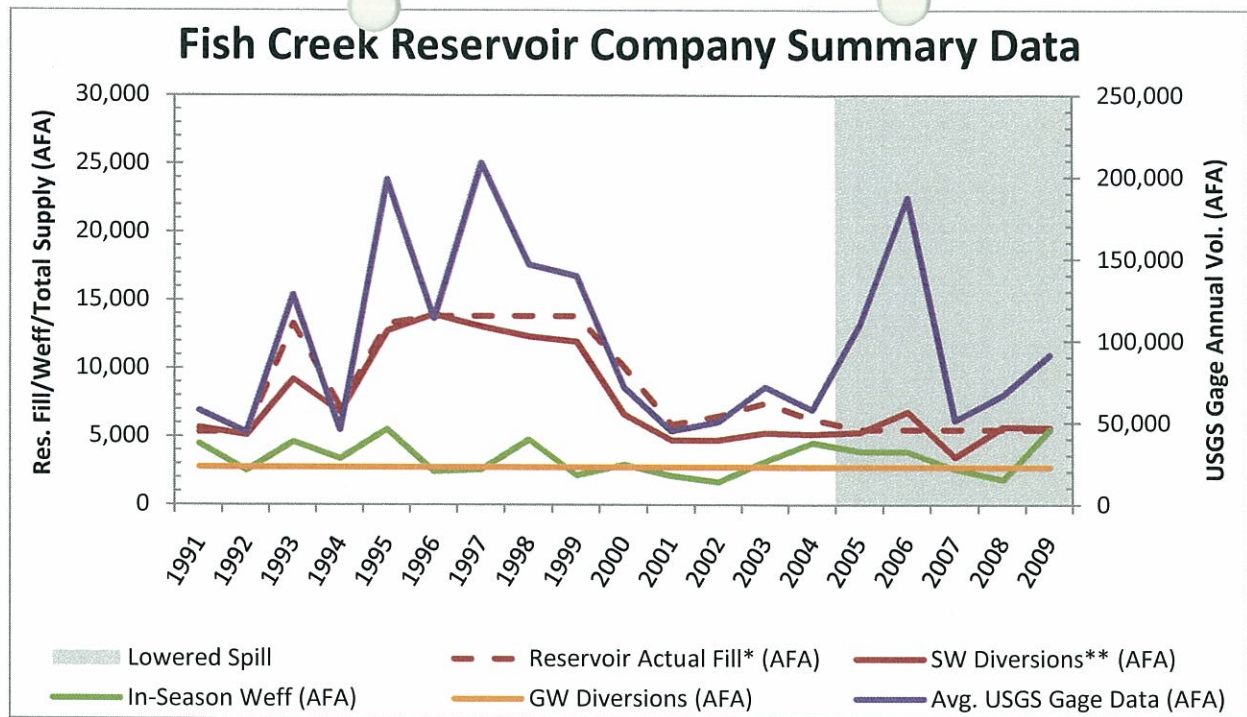
WR No.	Members of P&C Irr. Assn.	POU Acres	Surface WRs
37-2740	W.D. Pardue	543.7	Yes
37-2740	James Cenarrusa	198.6	Yes
37-2740	Zora Kenworthy (i.e. Judy)	81.4	Yes
37-2740	C.E. Molyneux (i.e. Chip or John)	364.7	Yes

Surface water rights are associated with all land that I identified as receiving supplemental ground water irrigation. Although ground water diversion records are not available⁷, the Watermaster has an anecdotal understanding of the diversion rates associated with each of the ground water rights identified, which he has shared with Brockway. On June 2, 2010 in an email correspondence Brockway provided the Watermaster's summary of ground water diversion rates throughout the season for each diversion. Based on this information I was able to construct season-long diversion functions (decreasing in most cases) for each of the ground water rights. Based on these diversion functions I estimated a season total diversion of ground water for each ground water right and from those estimates computed a season total diversion of 2,759 AF for all ground water rights. I have assumed that ground water diversions across the entire period of analysis are constant. Refer to the appendix for a summary of the methods used to determine a total annual ground water diversion volume within the FCRC service area, including the June 2, 2010 email from Brockway.

Total Supply

In determining total supply I considered the following information: effective precipitation, surface water diversion, storage fill, ground water diversion, and stream channel flow data. The following figure summarizes the time series for each of these sets of data for the period 1991-2009.

⁷ With the possible exception of 37-2740, which is conditioned to require the installation of a totalizing measuring device acceptable to the Department at all authorized points of diversion, which will allow determination of the total rate of diversion and the total diversion volume. These records were not reviewed as part of the analysis.



The following two tables summarize my calculations of individual and total water supply (Table 4) and the ratio of individual water supplies to the total supply (Table 5). Red shading indicates predicted values. Bold face type indicates years in which METRIC ET was calculated.

Table 4 - Fish Creek Reservoir Company Service Area Irrigation Supply Data

Year	In-Season W _{eff} (AFA)	SW Diversions (AFA)	GW Diversions (AFA)	Total Supply (AFA)
1991	4,448	5,646	2,759	12,853
1992	2,510	5,107	2,759	10,376
1993	4,594	9,214	2,759	16,567
1994	3,373	6,811	2,759	12,943
1995	5,508	12,725	2,759	20,992
1996	2,426	13,947	2,759	19,132
1997	2,575	13,055	2,759	18,390
1998	4,751	12,322	2,759	19,832
1999	2,154	11,958	2,759	16,871
2000	2,933	6,625	2,759	12,317
2001	2,110	4,747	2,759	9,616
2002	1,647	4,748	2,759	9,155
2003	3,155	5,246	2,759	11,160
2004	4,517	5,160	2,759	12,436
2005	3,896	5,309	2,759	11,964
2006	3,859	6,815	2,759	13,433
2007	2,610	3,504	2,759	8,873
2008	1,817	5,695	2,759	10,272
2009	5,510	5,658	2,759	13,928

Table 5 - Summary of Annual Ratios of Individual Supplies to Total Supply

Year	$W_{eff}/\text{Total (\%)}$	SW Div./Total (%)	GW Div./Total (%)
1991	34.6%	43.9%	21.5%
1992	24.2%	49.2%	26.6%
1993	27.7%	55.6%	16.7%
1994	26.1%	52.6%	21.3%
1995	26.2%	60.6%	13.1%
1996	12.7%	72.9%	14.4%
1997	14.0%	71.0%	15.0%
1998	24.0%	62.1%	13.9%
1999	12.8%	70.9%	16.4%
2000	23.8%	53.8%	22.4%
2001	21.9%	49.4%	28.7%
2002	18.0%	51.9%	30.1%
2003	28.3%	47.0%	24.7%
2004	36.3%	41.5%	22.2%
2005	32.6%	44.4%	23.1%
2006	28.7%	50.7%	20.5%
2007	29.4%	39.5%	31.1%
2008	17.7%	55.4%	26.9%
2009	39.6%	40.6%	19.8%

Total Irrigation Efficiency (E_i)

Total irrigation efficiency is a term used to describe the ratio of total volumetric crop water use (CWU) within a project boundary and the total volume of water diverted from the supply source (Fish Creek and aquifers) by all of the water users within that project to meet crop needs. Total irrigation efficiency (E_i) does not include losses in the reservoir or conveyance losses due to the conveyance of water from the reservoir to individual diversions from Fish Creek. E_i is calculated by the following equation (2):

$$(2) E_i = \text{crop water use} / (\text{surface water supply} + \text{ground water supply})$$

Crop water use (CWU) is the project wide volume of irrigation water supplied for crop growth. CWU is the difference between the estimated consumptive use associated with crop development, or ET, and effective precipitation. Crop water use is calculated as set forth in equation (3):

$$(3) CWU = ET - W_{eff}$$

The following table summarizes E_i values for the years 1996, 2000, 2002, and 2006. Included in the table are the input values of volumetric METRIC ET, in-season volumetric W_{eff} , total surface water diversions, and total ground water diversions.

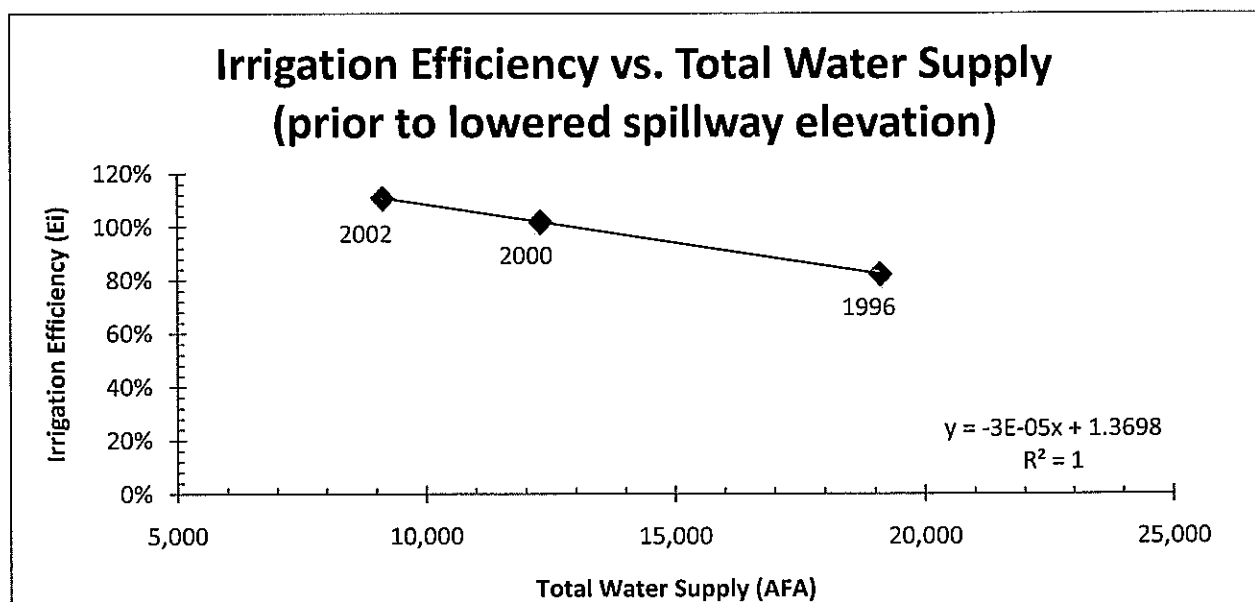
Table 6 - Summary of Calculated Irrigation Efficiencies

Year	METRIC ET (AFA)	In-Season W_{eff} (AFA)	SW Diversions (AFA)	GW Diversions (AFA)	E _i (%)
1996	16,169	2,426	13,947	2,759	82.3%
2000	12,485	2,933	6,625	2,759	101.8%
2002	9,964	1,647	4,748	2,759	110.8%
2006	14,896	3,859	6,815	2,759	115.3%

FCRC has proposed measuring and reporting the season total volume of water diverted into the recharge site (V_{weir}). The Department will only recognize the portion of V_{weir} that is equivalent to the historical consumptive losses from the system for recharge credit consideration. Equation (4) illustrates how a V_{weir} and E_i can be used to calculate the volume of water that the Department will acknowledge as new recharge to the aquifer for a specific water year:

$$(4) \text{ Recharge volume} = E_i * (V_{weir})$$

The next question to address is how to apply the irrigation efficiencies (E_i), determined from the METRIC analysis, to the end of season calculation of recharge volume. Because irrigation efficiencies after 2005 are influenced by a more limited water supply due to the lowering of the spillway, it is appropriate to limit the utilization of the historic E_i data to those years that predated the lowering of the spillway. A simple means of implementing the E_i findings would be to take a straight average of E_i values from 1996, 2000, and 2002. However, one shortcoming to this approach is that it does not rely on the actual water supply conditions of the year under consideration. Therefore, I propose a second approach in which a linear relationship is established between total water supply and E_i , whereby E_i can be calculated based on the total water supply for the current water year not to exceed 100%. A calculation of total water supply prior to 2005 would have included storage water that is now lost to the system. Therefore, in calculating total water supply for future years the volume of water measured at the weir (V_{weir}) would be included in the calculation. The following figure illustrates the x-y scatter plot of total water supply versus E_i and the established linear relationship prior to the lowering of the spillway in 2005.



Recognizing an additional contribution to recharge volume from new canal losses (V_{CL}) that developed as a result of the lowered spillway⁸, equation (4) can be modified as follows to compute a total recharge volume:

$$(5) \text{ Recharge volume} = E_i * (V_{weir} + V_{CL})$$

Finally, beyond the volume of water recognized for recharge associated with the historic consumptive component of water applied for irrigation, is the volume of water saved to the system from decreased reservoir surface evaporation (V_{evap}) due to a decreased reservoir surface area in conjunction with the lowered spillway. It is appropriate to add this term onto the recharge volume calculated with equation (5). Equation (6) can be used to calculate the final recharge credit to be recognized by the Department subject to limitations:

$$(6) \text{ Recharge Credit} = \text{Recharge Volume} + (V_{evap})$$

It is possible for equation (6) to yield a value for recharge volume in excess of foregone storage; therefore, it is necessary to limit the value produced from equation (6) to the foregone storage volume of 8,896 AF in those years where foregone storage is less than the calculated recharge credit.

Conclusion

My findings and analysis as presented in this memo outline a possible method in which a recharge credit can be calculated, specific to the conditions of the year, for which the Department can recognize a beneficial use of recharge to the aquifer that did not historically occur. As previously described in greater detail, the recharge credit is determined based on historical irrigation efficiencies as established by METRIC analysis, the calculated total water supply for the irrigations season, and the measured volume of water diverted to the recharge site plus some minor considerations. As necessary the recognized recharge will be limited to foregone storage in those years when the water available for diversion to the recharge site exceeds foregone storage.

Please refer to the following step by step example of the proposed process for calculating a recharge credit in association with the Fish Creek Reservoir Company's lost storage water.

⁸ The Department acknowledges that following the January 7, 2010 coordination meeting with Brockway and FCRC, credit shall be given for canal losses in the creek due to the diversion of water for recharge that occurs prior to the average historical day that "first water" has been in the creek due to spill or manual release of storage water.

Example

The following is an example implementing the methodology outlined in this memo to calculate a recharge credit for a fabricated water year in which it is assumed that the volume of water measured at the weir is equal to 7,500 AF and the total water supply was estimated to be 13,100 AF.

Step 1

Calculate Total Water Supply: In Season W_{eff} + SW Diversion + GW Diversions + V_{weir} = 13,100 ac-ft

Step 2

Calculate Irrigation Efficiency (E_i): $E_i = (-2.86E-5) * (\text{Total Water Supply}) + 1.37$

$$E_i = (-2.86E-5) * (13,100 \text{ ac-ft}) + 1.37 = 0.995$$

Step 3

Calculate Recharge Volume: Recharge Volume = $E_i * (V_{weir} + V_{CL})$

$V_{CL} = R * S$, where R is a ratio of the number of days new canal losses accrue and the total number of days in the irrigation season and S represents total seepage losses⁹. For the purposes of this example it is assumed 6 days represents the total time in which new canal losses occurred; 6 days represents the difference between April-15 (start of irrigation from storage) and April-21 (day of "first water"¹⁰).

$$R = 6/200 = 0.03$$

$$S = [(s/(1-s)) * V_{weir} * r] = (0.185/(1-0.185)) * (8,896 \text{ ac-ft}) * 1 = 2,019 \text{ ac-ft}$$

$$V_{CL} = 0.03 * (2,019 \text{ ac-ft}) = 60.56$$

$$\text{Recharge Volume} = 0.995 * (7,500 \text{ ac-ft} + 61 \text{ ac-ft}) = 7,523 \text{ ac-ft}$$

Step 4

Calculate Recharge Credit: Recharge Credit = Recharge Volume + V_{evap}

⁹ The expressions for V_{CL} and S and the value of 0.185 for "s" (ratio of seepage losses and volume spilled), are taken from Brockway's Aquifer Recharge Plan for the Fish Creek Reservoir Company Preliminary Revision B document dated June 15, 2009. For the illustrative example "r" (estimated fraction of the total stream flow that is foregone storage) is equal 1.0, since canal losses are only considered for those days prior to "first water" and it is assumed that all water from this time period represents foregone storage. In recognition of the fact that V_{CL} has a relatively small contribution to the overall recharge credit, the Department would support the use of a constant value for V_{CL} to be used year in and year out as a means of simplifying the overall methodology and calculations.

¹⁰ Relying on April 21 as the "day of first water" was established by Brockway and presented to the Department in a teleconference meeting dated June 9, 2010.

V_{evap} is the value of evaporative losses saved to the system due to the lowering of the spillway and the subsequent decrease in reservoir surface area less the increased evaporation is association with the surface area of the new recharge pond

$$V_{\text{evap}} = 257 \text{ ac-ft}^{11}.$$

$$\text{Recharge Credit} = 7,523 \text{ ac-ft} + 257 \text{ ac-ft} = 7,780 \text{ ac-ft}$$

Step 5

Evaluate Foregone Storage Limitation and determine the final recharge credit volume.

$$\text{Final Recharge Credit} = \min \begin{cases} 8,896 \text{ ac-ft (foregone storage)} \\ 7,780 \text{ ac-ft (Step 4 recharge credit)} \end{cases}$$

$$\text{Final Recharge Credit} = 7,780 \text{ ac-ft}$$

¹¹ 257 acre-feet is the volume of evaporative losses saved to the system due to the lowering of the spillway and the subsequent decrease in reservoir surface area (271 AF) less the increased evaporation is association with the surface area of the new recharge pond (41 AF). These values were reported by Brockway in their Aquifer Recharge Plan for the Fish Creek Reservoir Company Preliminary Revision B document dated June 15, 2009.

Appendix

Supplemental Material

Brockway Engineering Memo from April 1, 2010

Bill Kramber's Memo on METRIC ET for Fish Creek Reservoir Company

Fish Creek Reservoir Area Map Depicting Ground Irrigated with FCRC Water above the Reservoir

Regression Analysis Used in Predicting Surface Water Diversion Volumes for Years of Missing Data

Analysis Used in Estimating Season Total Ground Water Diversion Volume, including Brockway Email from June 2, 2010