Aspect CONSULTING

MEMORANDUM

Project No.: 090180-001-19

August 31, 2012

To: Mark Schuppe
Watershed Permitting Unit Supervisor
Washington State Department of Ecology
Central Regional Office

cc: Dick Ewing, Twin Lakes Aquifer Coalition

State of Washington Hydrogeologist 1537 Licensed Geologist

8-31-12

Erick William Miller

PETER S. BANNISTER STATE OF WASHINGTON 40776 REGISTERED PROFESSIONAL ENGINEER

From: **Erick W. Miller, LHG** Senior Associate Hydrogeologist
Peter S. Bannister, PE Senior Engineer
Timothy J. Flynn, LHG, CGWP Principal Hydrogeologist

Re: **Preliminary Feasibility Assessment of Multipurpose Storage**
Twin Lakes Area
Okanogan County, Washington

1 Introduction

1.1 Purpose and Scope

This memorandum evaluates the feasibility of water storage to address multiple water resource needs in the Twin Lakes area and Methow River Basin. The work was performed under contract to Washington State Department of Ecology Contract No. C0500006, Amendment 8. The analysis presented herein builds upon hydrogeologic evaluations and groundwater modeling completed to date related to processing of Twin Lakes Aquifer Coalition (TLAC) groundwater right application G4-34915. Previous evaluations focused on raising water levels in Big Twin Lake for recreational and habitat enhancement purposes by pumping groundwater sourced near the Methow River solely to Big Twin Lake. This memo summarizes additional evaluation of water storage options and associated benefits to streamflow that result from lake seepage. The TLAC project area is shown on Figure 1. The draft of this memorandum was issued on August 20, 2009.

The TLAC groundwater right application requests a maximum withdrawal rate of 4,500 gallons per minute (gpm) and a quantity of 2,000 acre-feet per year (afy) from wells located near the Methow River. The proposed purpose of use is restoration of water levels in Barnsley and Twin Lakes and the associated aquifer by recharge of pumped groundwater. The TLAC groundwater right application was evaluated by Aspect Consulting in a hydrogeologic report under Ecology's cost reimbursement program (Aspect, 2009). The hydrogeologic technical report provided technical analyses to assist Ecology in evaluating whether the TLAC application meets the criteria for expedited processing as defined under 173-152-050 Washington Administrative Code (WAC) (Hillis Rule). The hydrogeologic report also examines the storage quantity, seasonal variations in lake levels, and the timing and magnitude of return flow to the Methow River.

This study evaluates the feasibility of increasing storage in the project area by adding water to Barnsley and Big Twin Lakes, and directly to the aquifer via infiltration using infiltration galleries to restore lake levels and provide additional base flow to the Methow River. The return flow to the Methow River could be used for mitigation of new, out of stream appropriation and/or to enhance in-stream flows in the Methow River .

As part of this investigation, additional topographic survey data was collected to provide a better elevation model, an improved estimate of the storage volume available at each of the lakes, and an initial identification of low points that could result in flooding. Past surveying had indicated significant inaccuracies in the digital elevation model (DEM) for the area.

The remainder of this introduction presents a summary of findings and model results. Section 2 presents a brief description of the new elevation data that was obtained. Section 3 describes improved model calibration using the topographic survey results. Predictive simulations are presented in Section 4 and include a description of the modeled scenarios and model results. Results of a sensitivity analysis of various model parameters are discussed in Section 5.

1.2 Summary of Findings

The groundwater model (Aspect, 2009) was recalibrated based on the new topographic survey elevation data and improved estimates of evapotranspiration. The model recalibration improved the overall calibration of the model and significantly improved calibration of lake levels.

Predictive scenarios were modeled for annual diversion quantities of 200 afy, 300 afy, and 400 afy, using the recalibrated model. In addition, withdrawals under the Washington Department of Fish and Wildlife (WDFW) specified window (about 270 afy average) were re-run using the recalibrated model to evaluate changes to the water balance as a result of the model recalibration. With the exception of the WDFW scenario, withdrawals were evenly divided between the months of April 1 through September 30 for each scenario. For example, in the 300 afy scenario, 50 acre-feet (af) were withdrawn monthly for the 6-month withdrawal period. A 300 afy "late" scenario was also developed that compressed withdrawals to the period of July 1 through September 30 to evaluate the effects of varying the timing of lake augmentation on the timing of Methow River return flows. In addition to maximizing the annual storage quantity, the scenarios targeted achieving a lake elevation of 1,798 feet in Big Twin Lake. The model scenarios also assumed that water diversion would only occur during the irrigation season. Model results are summarized in Table 1.

Table 1 – Model Results Summary – Multipurpose Storage Assessment
TLAC Water Right Application

Scenario	Years to fill Big Twin Lake to target elevation of 1,798 feet	First Year Water is available to Barnsley Lake	First Year Water is available to infiltration galleries	Average October-March Methow River Return Flow (gpm) (1)	Methow River Return Flow (percent of total withdrawal) (1)	Increase in Et (afy)(1)
200 afy	Does not fill. Achieves elevation 1,796	Unavailable	Unavailable	78	64%	61
300 afy	8 to 10	10	12	116	64%	95
300 afy late	6 to 7	7	8	122	66%	90
400 afy	4	5	5	164	68%	110
WDFW	3 to 4	Unavailable	Unavailable	102	61%	85

(1) Value based on average of last 5 years of model run.

Under each scenario, groundwater is pumped and conveyed toward Big Twin Lake. Filling Big Twin Lake is assumed to be the highest priority in each scenario, and was accomplished by direct discharge to the lake. Infiltration galleries were simulated at a location suggested by TLAC, about ¼ mile northwest of Big Twin Lake. Geotechnical investigation would be necessary to confirm the suitability of this location. Direct discharge was preferred over use of infiltration galleries as a portion of the water diverted to the infiltration gallery would likely flow northward and not contribute to filling Big Twin Lake. Once the Big Twin Lake target level is reached, water is diverted into Barnsley Lake. The target lake levels in Big Twin and Barnsley Lakes are 1,798 and 1,780.5 feet, respectively. Water is diverted to the infiltration galleries only after target lake levels in Big Twin and Barnsley Lakes have been obtained.

Based on comments received on the draft of this memorandum at a meeting with TLAC and Ecology, an infiltration-only scenario was developed where 400 afy was recharged entirely through the infiltration galleries. Results of the infiltration-only scenario are presented in Attachment A.

Under the 200 afy scenario, the quantity of water is insufficient to fill Big Twin Lake to the target level. The model indicates that about 250 afy is the minimum necessary to reach target lake elevations at Big Twin Lake.

Big Twin Lake target levels are reached in about 4 years under the 400 afy scenario and water is then diverted to Barnsley Lake. Barnsley Lake has a relatively small storage volume, fills during the fourth year, and water is then diverted to the infiltration gallery. The lake fill time for the 300

afy scenarios ranges from about 6 to 8 years (Table 1). Under the infiltration-only scenario, the target lake level in Big Twin Lake is not achieved. Target lake level in Barnsley Lake is achieved in about Year 3, but fluctuates about 2 feet annually (Figure A-1).

An equilibrium condition is approached in the aquifer after about 10 years of project operation under each of the scenarios. Under the equilibrium condition, groundwater levels achieve a near-constant level, no longer exhibiting annual increases in response to lake seepage, and water losses are limited to evapotranspiration and Methow River return flow. Under each of the scenarios at equilibrium conditions, approximately 65% of the water withdrawn and used to amend lake levels returns to the Methow River. The balance of the water is lost to evapotranspiration.

The timing of return flow is fairly evenly distributed throughout the year. From October through March, when TLAC pumping is not occurring return flow will increase streamflow. During the pumping periods, return flow only partially offsets pumping impacts to streamflow and a net decrease in streamflow occurs.

Assuming a water right or rights totaling 300 afy or greater could be obtained, model results indicate the following projects benefits would be recognized:

- Higher lake levels in Big Twin, Little Twin, Barnsley, and Dibble Lakes and the associated benefit to biologic communities. All lakes would be filled to target elevation within a 4- to 10-year time frame;
- An increase in aquifer levels in the Twin Lakes aquifer up to 8 feet.
- An increase in Methow River flows during the period from October through March when streamflows are lowest; and/or,
- Mitigation water for downstream users seeking new water rights for out of stream uses, particularly during the winter months.

2 Field Investigation - Improved Topographic Definition

Topographic control in the Twin Lakes area was initially obtained from the 10-meter U.S. Geological Survey (USGS) DEM. Data associated with the USGS 10-meter DEM file indicates that it was created by digitizing from 40-foot elevation contours. Within the study area, and particularly in the area around Big Twin, Little Twin, Barnsley and Dibble Lakes, the variations in topography that occur between the 40-foot contour control is substantial, and has a significant effect on estimated lake storage capacity and evapotranspiration. For example, the DEM indicates that Barnsley Lake falls between the 1,840- and 1,800-foot elevation contours and has a lake elevation of about 1,825 feet. The topographic survey determined an actual lake elevation of about 1,775 feet, indicating about a 50-foot error in the DEM. Similarly, much of the relatively flat shoreline surrounding Big Twin Lake is lost at the resolution of the DEM.

To improve the groundwater model and estimates of lake storage capacity, 292 additional points were surveyed by a licensed surveyor (Erlandsen and Associates) in the areas surrounding Barnsley and Twin Lakes in May 2009. These points supplemented previously surveyed elevations of approximately 45 wells surveyed by Aspect/Erlandseen and Associates and lake level elevations in Barnsley, Twin Lakes and Dibble Lakes, and elevations surveyed by the USGS. The DEM was adjusted to match the surveyed data.

3 Model Update and Recalibration

The groundwater model, developed by Aspect (2009), was recalibrated using the updated topographic elevation data. This resulted in significant improvement to the model calibration in the vicinity of the Twin Lakes. The greatest improvement was observed in the calibration of lake levels. Figure 2 presents the final model calibration statistics. A good model calibration has a standard deviation of the ratio water level differences/range in water levels of less than 10%. For the Twin Lakes model, this value is 6% indicating a good model calibration.

Initial efforts to calibrate the model to surveyed water levels at Barnsley Lake yielded modeled lake levels that were significantly lower than those observed. To match observed water levels in Barnsley Lake, a thin zone of the unconsolidated aquifer unit north of Barnsley Lake was simulated with lower permeability. Well log data is relatively sparse in this area, but the variability observed in the few logs in the northeast quarter of the northeast quarter of Section 10 (10D) T34N, R21E, between Barnsley Lake and the Methow River, indicates that significant lithologic variations, and corresponding variations in aquifer permeability, occur within the unconsolidated deposits in this area. In addition, nearby shallow bedrock suggests the potential for a buried subsurface bedrock feature with the potential to impede groundwater flow. The groundwater model includes a similar low permeability feature east of Dibble Lake and is described in the *Hydrogeologic Evaluation Report* (Aspect, 2009).

The upper 50 feet of bedrock was modeled with slightly higher permeability than deeper bedrock, to represent a fracture/weathered zone. The model would not converge with the high contrast in permeability between the lower aquifer and the bedrock. An intermediate permeability was used in the top layer of bedrock for transition. Parameter Estimation (PEST) was used to determine the best K value for the top layer of bedrock.

The evapotranspiration (ET) rate was also reviewed and adjusted. Table 2 presents a summary of estimates of reference crop ET and pan evaporation in the vicinity of Winthrop. Datasets used to estimate ET in the vicinity of Winthrop are generally limited by short periods of record and/or large data gaps. The model was recalibrated using the 40 inches per year (in/yr) evapotranspiration rate estimated for Wenatchee by the WSU Agricultural Weather Network (www.weather.wsu.edu). Previous modeling efforts used relatively conservative ET estimates based on the Yakima climate station data with the longest period of record. Proximal ET estimates ranged from 35 in/yr based on pan evaporation data in Oroville to a high of 43 in/yr using the USGS Jensen-Haise method. In general, the pan evaporation data gives a lower estimate of ET than the reference crop methods (Table 2). The Penman1963 method using Wenatchee climate data is similar to the Winthrop estimated ET value (40 vs. 42 inches annually), while the Yakima values give an upper bound for ET. The SCS Blaney-Criddle method using Winthrop climate data is judged to be representative due its proximity to the site, but the Blaney-Criddle method may result in a slight underestimate of ET (Jensen and others, 1990); therefore, the Wenatchee ET rate computed from a combination method (Penman, 1963) was used in the model.

4 Predictive Simulations

The calibrated model was used to predict lake level changes and return flow quantities for water storage scenarios. Five scenarios were developed to explore potential benefits and impacts from a range of lake amendment quantities. This section first describes the TLAC augmentation scenarios and then presents model results.

The monthly river boundary conditions are based on the historic, 17-year streamflow record for the Methow River from 1989 through 2006. The streamflow record for 1989 was simulated as year 2010 in the predictive model. Average monthly recharge was calculated based on historical precipitation and irrigation practices.

4.1 Model Scenarios

Predictive model scenarios were run to evaluate the relationship between annual diversion quantity storage within Barnsley and Twin Lakes, storage in the aquifer, and return flow to the Methow River.

Previous predictive modeling of water storage had focused on compliance with the WDFW withdrawal window to meet criteria for expedited processing under the Hillis Rule. This WDFW withdrawal window was specified as April 1 to July 15 and when flows at the Methow River at Winthrop gage station are between 800 and 6,000 cubic feet per second (cfs). For the TLAC application to meet the criteria for expedited processing under Hillis Rule, it must provide a net environmental benefit and be water budget neutral. WDFW indicated that the proposed project, with certain specified permit conditions, will provide for substantial environmental benefit by enhancing the trout fishery in Big Twin Lake. Among the permit conditions was restricting withdrawals to the WDFW specified withdrawal window. Previous modeling focused on the WDFW withdrawal window and processing of the water right application under the Hillis Rule.

The focus of the new modeling effort was to assess the feasibility and benefits of increased lake and aquifer storage. The following scenarios were evaluated using the recalibrated model:

Existing Buildout – This simulation was used for model calibration using existing buildout of parcels within the study area, including exempt and non-exempt wells.

Full Buildout – This simulation evaluates effects of full buildout of mapped parcels within the study area. New exempt wells simulated to be completed in bedrock and are situated in the center of currently unoccupied tax parcels to supply domestic needs. There is no diversion of water for storage and lake level augmentation under this scenario.

WDFW Scenario – This scenario simulates TLAC transfer of water from wells located in close proximity to the Methow River (as described in the TLAC water right application and shown on Figure 1) to Big Twin Lake. The proposed well locations are shown on Figure 1. Withdrawals are limited by the WDFW withdrawal window described above and assume 1,000 gpm system capacity. Full buildout is assumed in this scenario.

200, 300 and 400 afy Scenarios – These scenarios simulate the transfer of 200, 300, and 400 afy from wells located in close proximity to the Methow River (assumes same well locations described in the TLAC water right application and shown on Figure 1) to a combination of Big Twin Lake, Barnsley Lake, and an infiltration gallery. Withdrawals are distributed equally from

April 1 through September 30 and assume 1,000 gpm system capacity. Modeled withdrawals during this time period comply with base flows established in 173-548 WAC at Winthrop. Mitigation would be required to meet the minimum instream flow (MIF) at Pateros for some years. Full buildout is assumed in this scenario.

300 afy Late Scenario – This scenario is similar to the 300 afy scenario described above. However, the withdrawal is limited to the period from July 1 through September 30 in an effort to maximize return flow to the Methow River during the fall and winter, and assume 1,000 gpm system capacity. Modeled withdrawals during this time period comply with base flows established in 173-548 WAC at Winthrop. Mitigation would be required to meet the minimum instream flow (MIF) at Pateros for some years. Full buildout is assumed in this scenario.

Infiltration-Only Scenario – Based on comments received on the draft of this memorandum, an infiltration-only scenario was developed where 400 afy is recharged entirely through the infiltration galleries. Results of this scenario are presented in Attachment A. Full buildout is assumed for this scenario.

4.2 Model Results

Model results are presented in the following figures:

Figure 3 – Annual Diversion Quantities – Presents the annual diversion quantity delivered to Big Twin Lake, Barnsley Lake and the infiltration gallery for each scenario.

Figure 4 – Monthly Diversion Quantities – Presents the average monthly diversion quantity delivered to Big Twin Lake, Barnsley Lake, and the infiltration gallery for each scenario, based the last 5 years of model simulation.

Figure 5 – Observed and Calculated Lake Levels – Presents observed lake level fluctuations since monitoring began in 2006 with model- predicted lake levels for each of the scenarios. Predicted lake level elevations are shown for Big Twin, Barnsley, and Dibble Lakes. Observed lake level data indicate that Big and Little Twin Lakes fluctuate in a similar manner and are in direct hydraulic communication.

Figure 6 – Annual Water Balances – Predicted changes to the water balance components are presented for each scenario for each year of the model period. For comparison purposes, the results have been offset by the effects of future buildout (i.e., future buildout is the base case for evaluating project changes; therefore, changes are shown relative to existing conditions). Water balance components shown in Figure 6 from top to bottom include:

- Change in evapotranspiration due to lake level increases and increase in lake areas;
- Quantity of lake seepage that returns toward the upper reach of the Methow River (near the point of withdrawal) as groundwater, termed “Return Flow”;
- Quantity of lake seepage that returns to lower reach of the Methow River southeast of Twin Lakes (bypass reach), termed “Bypass”; Quantity of water that fills lake and aquifer storage; and

- Sum of Return Flow, Bypass, and lake and aquifer storage. These components are under discussion as contributing to the total mitigation quantity for a water budget neutral project.

Figure 7 – Monthly Water Balances – Predicted changes to the water balance components on a monthly basis are presented for each scenario consistent with the annual water balance. For comparison purposes, the results have been offset by the effects of future buildout.

Figure 8 – Summary of Total Return Flow to Methow River – This figure summarizes model results in terms of Methow River return flow. The top graph presents groundwater discharge rates to the Methow River during the late fall and winter months. The middle graph presents cumulative groundwater discharge to the Methow River throughout the year. The bottom graph shows the percent of total withdrawals that returns to the Methow River.

4.3 Lake Level Augmentation

As discussed previously, the filling of Big Twin Lake is considered a priority under each of the scenarios. A discussion of the timing and level of lake fill is presented below for each scenario.

200 afy Scenario – Approximately 33 af/month is diverted to Big Twin Lake under the 200 afy scenario (Figure 4). Lake seepage and evaporation consume the lake amendment quantities and no water is available for diversion to Barnsley Lake or the infiltration galleries. The maximum Big Twin Lake level achieved by filling under the 200 afy scenario is about elevation 1,796, about 2 feet lower than the target elevation (Figure 5). Barnsley Lake levels are predicted to increase gradually to a maximum lake elevation of 1,777 as groundwater levels rise in response to Big Twin Lake augmentation under this scenario. This is about 2 feet higher than observed lake levels (Figure 5) and about 3 feet less than the target elevation.

300 afy Scenario – Monthly diversions are increased to 50 af/month under the 300 afy scenario. The target Big Twin Lake level target elevation is reached in about year 8 (Figure 5). Water becomes available for Barnsley Lake in year 10 and a small quantity becomes available to the infiltration galleries in year 12 (Figure 3). On a monthly basis, water for Barnsley Lake and the infiltration galleries is available in April and May (Figure 4). A Barnsley Lake elevation of about 1,778 is achieved in the 300 afy scenario.

300 afy Late Scenario – Under the 300 afy late scenario, Big Twin target lake levels are achieved in about year 6 and water becomes available for Barnsley Lake in year 7 and to the infiltration galleries in year 8 (Figure 3). Water is diverted at the rate of 100 af/month and is only available to Barnsley Lake and the infiltration galleries in the month of September (Figure 4). A Barnsley Lake elevation of about 1,778 is achieved in the 300 afy late scenario seasonally fluctuating up to elevation 1780 during fill periods.

400 afy – Big Twin Lake reaches the target elevation by about year 4 (Figure 5) and water is available for diversion to Barnsley and the infiltration gallery in years 4 and 5, respectively (Figure 3). The annual average Big Twin Lake elevation is about 1-foot higher under the 400 afy scenario compared to WDFW scenario. Barnsley Lake fills to the target elevation in year 5.

WDFW Scenario – Monthly withdrawals under WDFW scenario are variable due to the specified WDFW withdrawal window. WDFW scenario fills Big Twin Lake in about 3 to 4 years, about the same time as the 400 afy scenario due to relatively greater water availability and higher

withdrawal rates simulated for the first years of operation (Figure 3). Once lake and aquifer storage is filled, the maintenance augmentation quantity is an average of 269 afy.

4.4 Evapotranspiration

Evapotranspiration increases as the lakes fill and their surface areas increase. The increase in evapotranspiration ranges from 61 afy to 110 afy (Figure 6). New survey data for the area surrounding Big Twin Lake indicates a broad, gradually sloped lake front that significantly increases the lake surface area per foot of lake stage change when compared to the DEM shoreline. This results in a significantly greater evapotranspiration estimate than was previously modeled. The increase in surface area is partially offset by a lower ET rate, with the net result of an overall increase in evapotranspiration, when compared to the previous model. The greatest monthly change in evapotranspiration occurs in July when ET rates are highest (Figure 7), with the exception of the 300 afy late scenario, where August slightly exceeds July.

4.5 Aquifer Storage

During the first years of pumping under each of the lake amendment scenarios, nearly all the water goes to replenish aquifer storage (Figure 6), with no appreciable rise in lake level to cause a significant increase in evapotranspiration. Water discharged into Big Twin Lake recharges the aquifer and raises groundwater levels. Aquifer storage builds and groundwater levels rise until an equilibrium (nearly zero change in lake and aquifer storage) is reached after about 10 years of pumping.

Monthly changes in aquifer storage under equilibrium conditions are presented in Figure 7. For the 200, 300 and 400 afy scenarios, aquifer storage builds from March through September, as diversion and lake seepage is at its greatest rate and exceeds Methow River return flow. From about October through March, lake and aquifer storage decline as return flow is discharged to the Methow River. Under the 300 afy late scenario, the period when aquifer storage increases is limited by the shorter lake amendment period from July through September. Under the WDFW scenario, aquifer storage increases during the lake amendment period from April through July.

4.6 Return Flow to Methow River

Return flow is water that is not consumed by evapotranspiration that flows toward the Methow River, and is eventually discharged to the Methow River or captured by TLAC wells. Big Twin Lake seepage that enters the aquifer flows north (upper reach) or southeast (bypass), toward the Methow River. Return flow from TLAC augmentation increases during the first 10 years of the project as aquifer storage is filled (Figure 6). Under the 400 afy scenario, about 200 afy returns toward the upper reach of the Methow River and about 60 afy returns to the Methow River via the bypass reach, after equilibrium is reached. For the 300 afy, and 300 afy late scenarios, return flows are similar at about 145 afy, to the upper reach and 50 afy to the bypass reach, respectively. Under the 200 afy scenario, about 90 afy returns toward the upper reach and 35 afy returns via the bypass reach. Equilibrium return flows under the WDFW scenarios fall between the 300 afy and 200 afy scenarios (Figure 6).

The timing of the return flow is fairly uniform throughout the year for both the upper and lower reaches under all scenarios (Figure 7). Thus, as aquifer storage builds and subsides on an annual cycle, the flow rate toward the river is largely controlled by the aquifer permeability. The average rate of groundwater discharged to the Methow River from October through March is about 164

gpm for the 400 afy scenario, 116 gpm for the 300 afy scenario, 122 gpm for the 300 afy late scenario, about 102 gpm for the WDFW scenario, and about 78 gpm for the 200 afy scenario (Figure 8, top graph).

The cumulative discharges to the Methow River, inclusive of pumping-related impacts on river flows, are presented in Figure 8, middle graph. Net discharge of project water to the Methow River occurs from October through March and the cumulative discharge peaks in March. As the source wells begin pumping in April, the water withdrawn exceeds the return flow and the cumulative discharge declines through late September when pumping ends. For the 300 afy late scenario, the period of net positive discharge extends from October through June, but the decline in cumulative discharge is greater in July through September when compared to the other scenarios due to the more compressed pumping schedule (Figure 8, middle graph).

The bottom graph in Figure 8 expresses return flow as a percent of the groundwater withdrawal. Under steady state conditions, about 61% to 68% of the pumped water returns to the Methow River as return flow for each of the scenarios. The greatest quantity of return flow on a percent basis occurs under the 400 afy scenario and the smallest percentage occurs in the WDFW scenario.

5 Sensitivity Analysis of Recalibrated Model

Ecology comments on the hydrogeology report (Aspect, 2009) requested additional sensitivity analysis of model input parameters. A sensitivity analysis was performed for the following parameters on the calibrated model:

1. Hydraulic conductivity;
2. Unconfined storage coefficient (specific yield);
3. Confined storage coefficient (specific storage); and
4. Recharge.

Results are presented in Figure 9. The greatest sensitivity was found for the hydraulic conductivity of the lower aquifer in the vicinity of Twin Lakes and low-permeability features bounding the Twin Lakes aquifer (low permeability zones north of Barnsley Lake and east of Dibble Lake). The model was also found to be somewhat sensitive to changes in shallow bedrock permeability. The model calibration was not found to be sensitive to changes within a range of literature values for specific yield or specific storage.

Of the recharge components, the model was most sensitive to the rate of irrigation return flow. The model was also sensitive to recharge rates for Thompson Creek, the areal recharge rate, and the recharge rate applied to Big Twin Lake representing direct precipitation and overland flow.

Sensitivity analysis was performed using PEST, which evaluates sets of parameter values over reasonable ranges to minimize the calibration error (Dougherty, 2002). Outside of PEST, the model calibration was found to be sensitive to evapotranspiration rates, although the relationship between diversion quantities and the water balance components remained relatively consistent.

6 References

Aspect Consulting, LLC (Aspect), 2009, Hydrogeologic Evaluation Report Water Right Application G4-34915, Twin Lakes Aquifer Coalition, Cost Reimbursement Project, prepared for Washington State Department of Ecology. Bainbridge Island, Washington. Unpublished Work. December 29, 2009.

Dougherty, J., 2002, PEST Model-Independent Parameter Estimation.

Jensen, M.E., Burman, R.D., and Allen, R.G., 1990, Evapotranspiration and irrigation water requirements: a manual/prepared by the Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the American Society of Civil Engineers, Abstract, ASCE Manuals and Reports on Engineering Practice No. 70.

Penman, H. L.,1963, Vegetation and hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England. 125 p.

Limitations

Work for this project was performed and this memo prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This memo does not represent a legal opinion. No other warranty, expressed or implied, is made.

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Attachments

Table 1 – Model Results Summary – Multipurpose Storage Assessment (In Text)
Table 2 – Evapotranspiration Estimates
Figure 1 – Twin Lakes Project Area (showing point of withdrawal)
Figure 2 – Model Calibration
Figure 3 – Annual Diversion Quantities
Figure 4 – Monthly Diversion Quantities
Figure 5 – Observed and Calculated Lake Levels
Figure 6 – Annual Water Balances
Figure 7 – Monthly Water Balances
Figure 8 – Summary of Total Return Flow to Methow River
Figure 9 – Model Parameter Sensitivity Analysis Results
Attachment A – Infiltration Only Scenario

Table 2 - Evapotranspiration Estimates

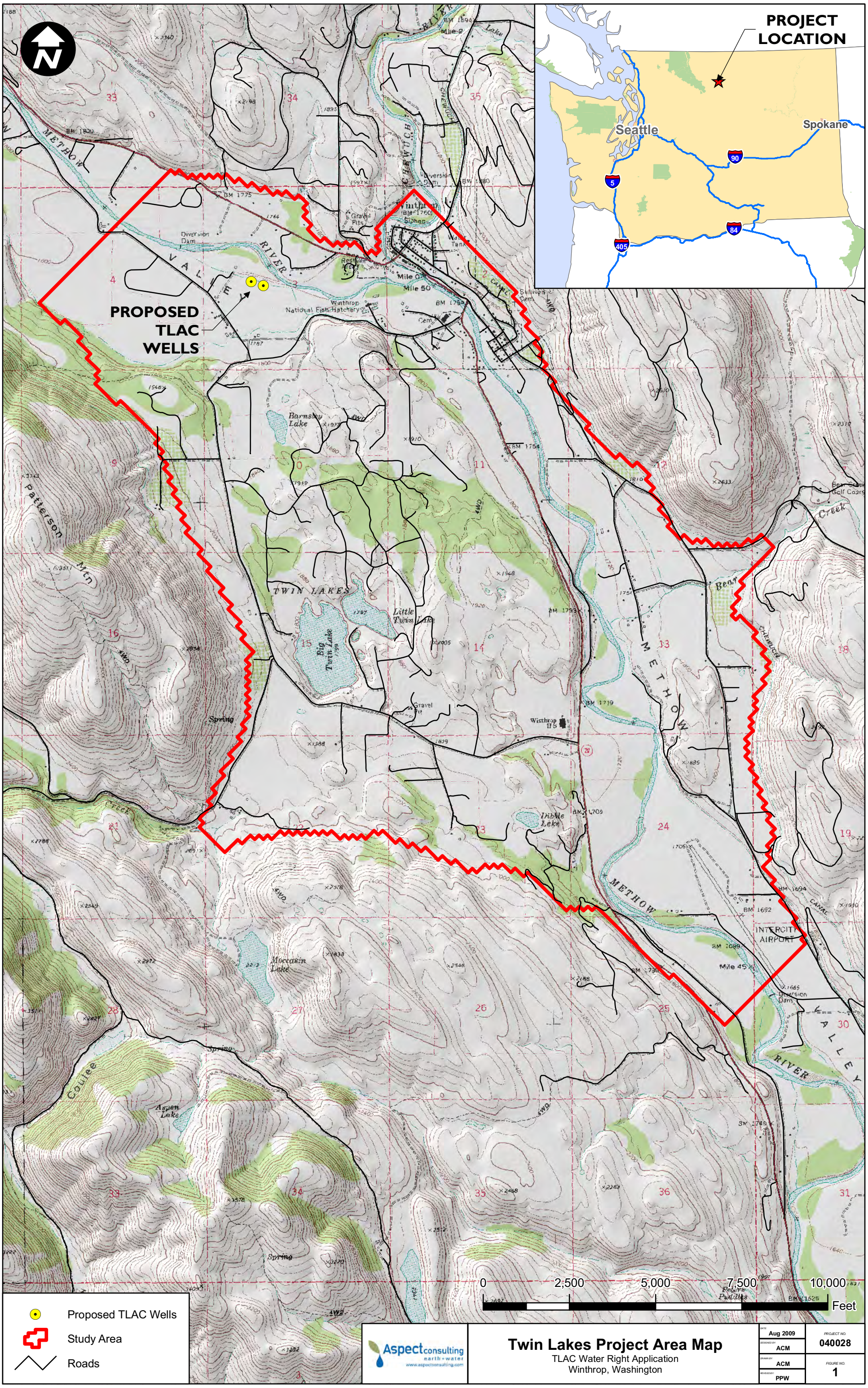
TLAC Water Right Application

Station	Method	Reference Crop	Crop Evapotranspiration Rate or Pan Evaporation	Crop Coefficient or Pan Factor	Estimated Lake Evapotranspiration	Source	Comments
Winthrop	SCS Blaney Criddle	N/A	40.3	1.0	40.3	Aspect	Based on Winthrop temperature data.
Methow Basin	Jensen Haise	Alfalfa	51.5	1.2	42.9	USGS (Ely, 2003)	Assumes USGS value reports alfalfa-referenced radiation method.
Wenatchee	Class A Pan	NA	48.5	0.8	38.8	WRCC	Average pan data 1950-1997. Pan not operated October through March. These months estimated from Penman 63 for Wenatchee PAWs station.
Pogue Flat	Penman 63	Grass	34.6	1.0	34.6	WSU PAWs	Based on 1 year period of record.
Oroville	Class A Pan	NA	42.8	0.8	34.2	WRCC	Average Pan data 1960 to 1970. Pan not operated November through March. These months estimated from Penman 63 for East Oroville PAWS station.
Wenatchee	Penman 63	Grass	41.9	1.0	41.9	WSU PAWs	

Open Water K factor based on average of early, mid and late season crop coefficients from (ASCE Manual 28).

WRCC = Western Regional Climate Center

WSU PAWs = Washington State University Public Agricultural Weather station


PROJECT LOCATION
Seattle
Spokane
90
5
84
405
PROPOSED TLAC WELLS
METHOW
VALLEY
RIVER
Winthrop
Winthrop National Fish Hatchery
Mile 50
Mile 45
Diversion Dam
Barnsley Lake
TWIN LAKES
Big Twin Lake
Little Twin Lake
Dibble Lake
Moccasin Lake
Aspen Lake
Patterson Mtn
Coulee
Bear Creek
INTERCITY AIRPORT
Spring
Gravel Pit
Proposed TLAC Wells
Study Area
Roads
0
2,500
5,000
7,500
10,000
Feet
Aspect consulting
earth • water
www.aspectconsulting.com
Twin Lakes Project Area Map
TLAC Water Right Application
Winthrop, Washington
DATE: Aug 2009
DESIGNED BY: ACM
DRAWN BY: ACM
REVISED BY: PPW
PROJECT NO. 040028
FIGURE NO. 1
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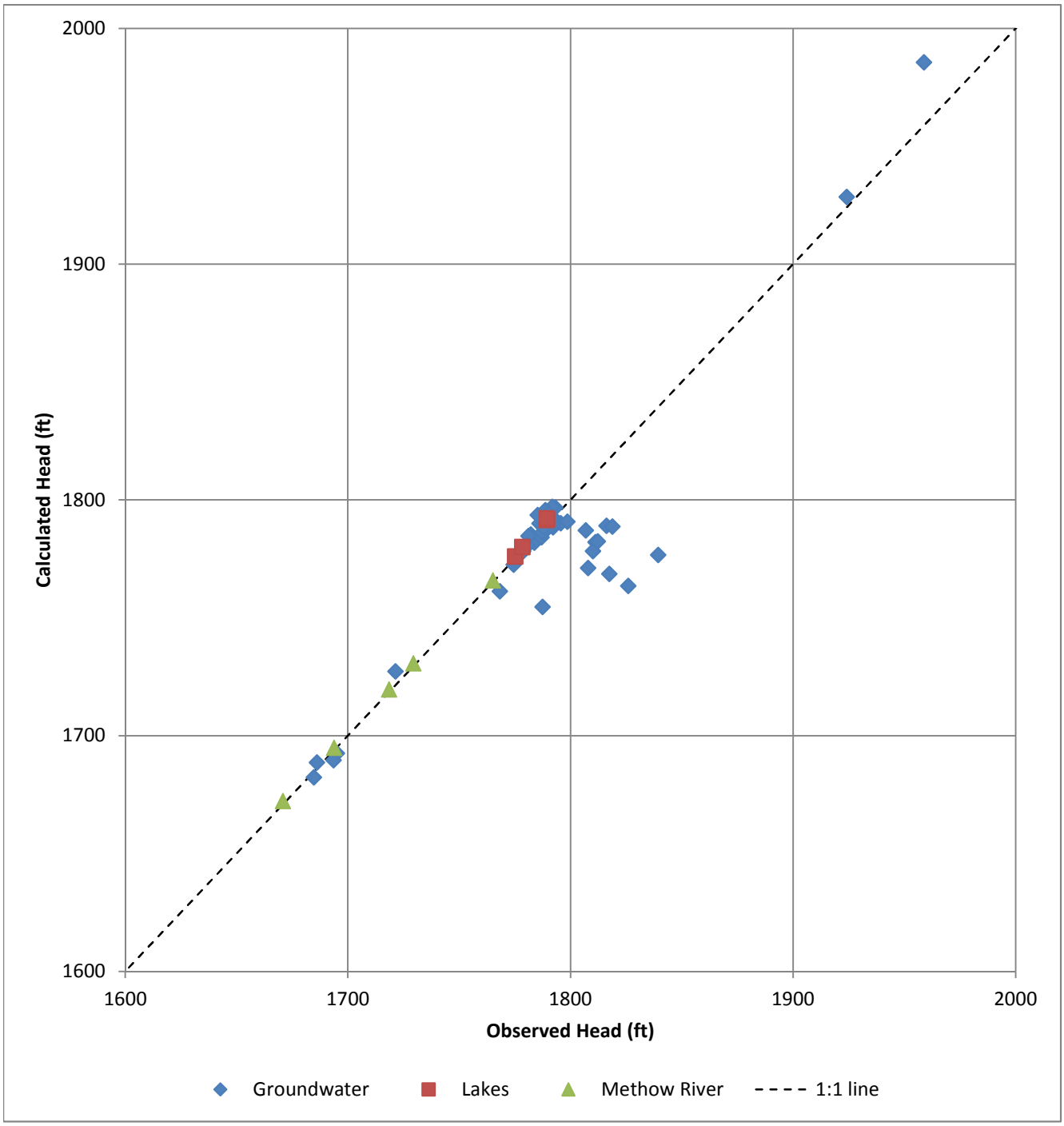

Model Calibration Statistics

	Groundwater	Surface Water	Overall
Residual Mean	8	-1	6
Res. Standard Deviation	18	1	17
Res. Sum of Square	18690	21	18711
Absolute Res. Mean	11	1	10
Min. Residual	-27	-3	-27
Max. Residual	63	-1	63
Range of Observed Values	274	119	288
St. Dev./Range	7%	1%	6%

Residual = Observed - Calculated

A "good" calibration has St. Dev./Range less than 10%.

Aspect Consulting, LLC
8/31/2012
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Figure 2
Model Calibration
TLAC Water Right Application
Winthrop, Washington

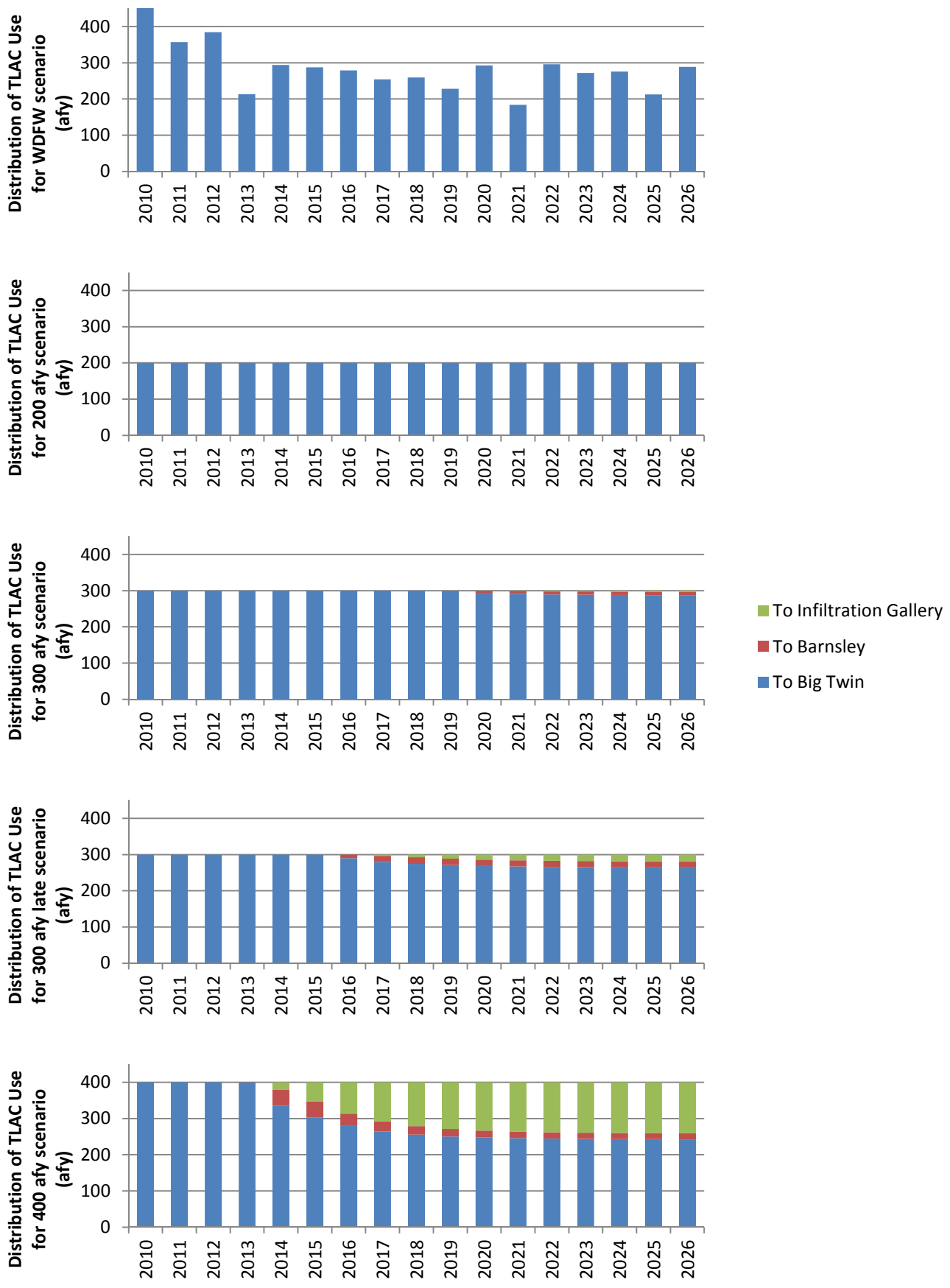

Figure 3
Annual Diversion Quantities
TLAC Water Right Application
Winthrop, Washington

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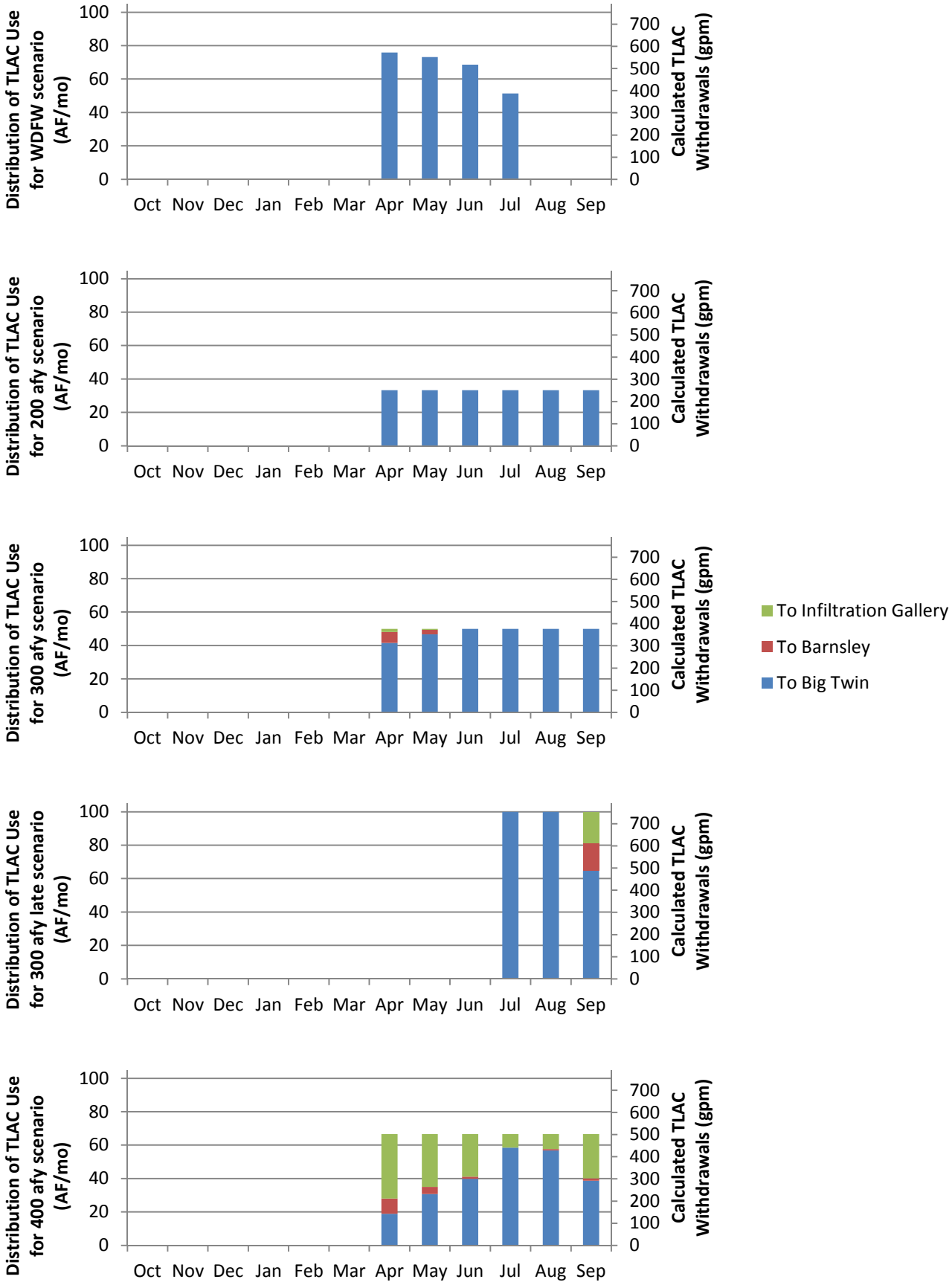

Values presented are average of last 5 years of model simulation.

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Figure 4
Monthly Diversion Quantities
TLAC Water Right Application
Winthrop, Washington

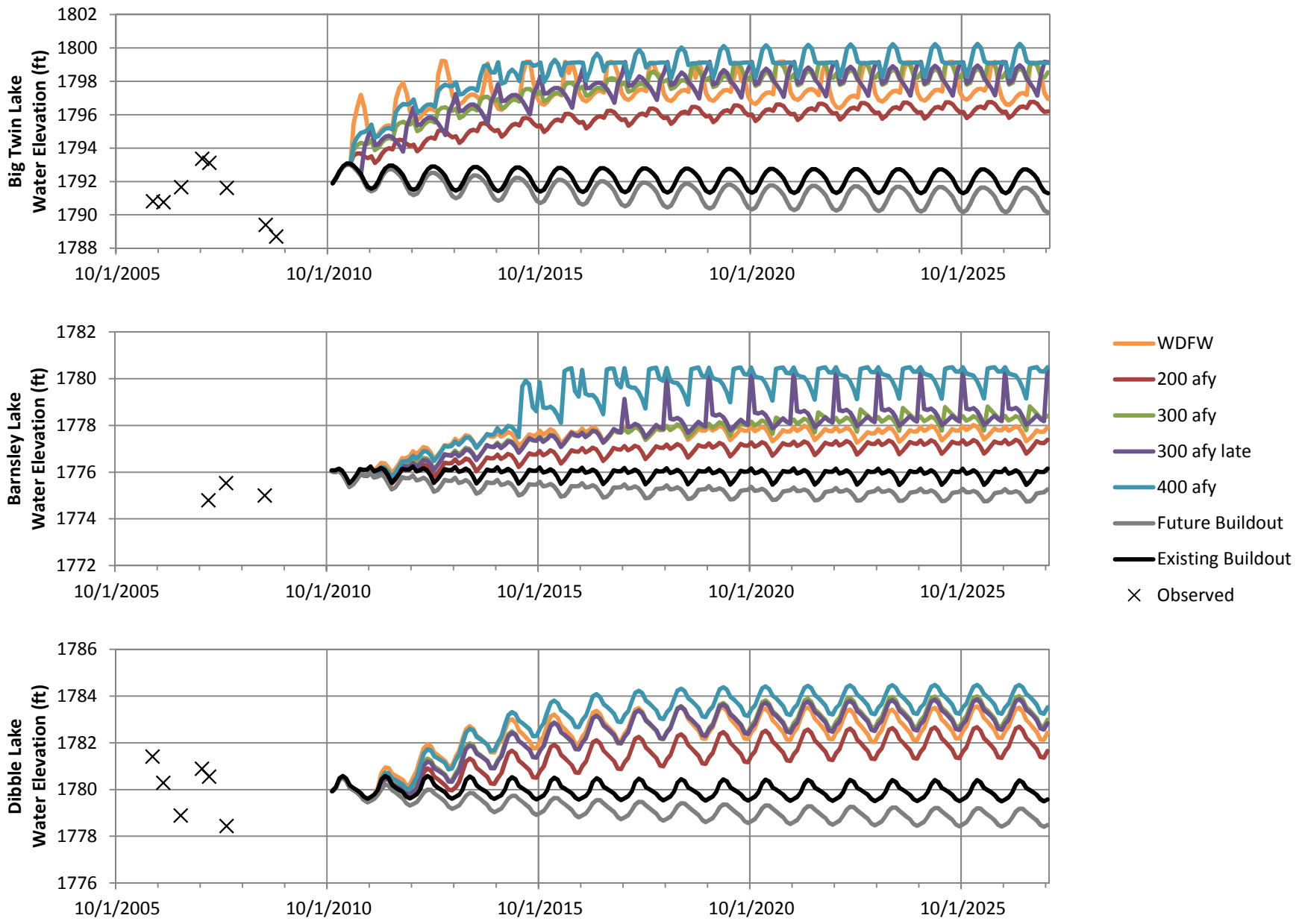

Figure 5
Observed and Calculated Lake Levels
TLAC Water Right Application
Winthrop, Washington

Aspect Consulting, LLC
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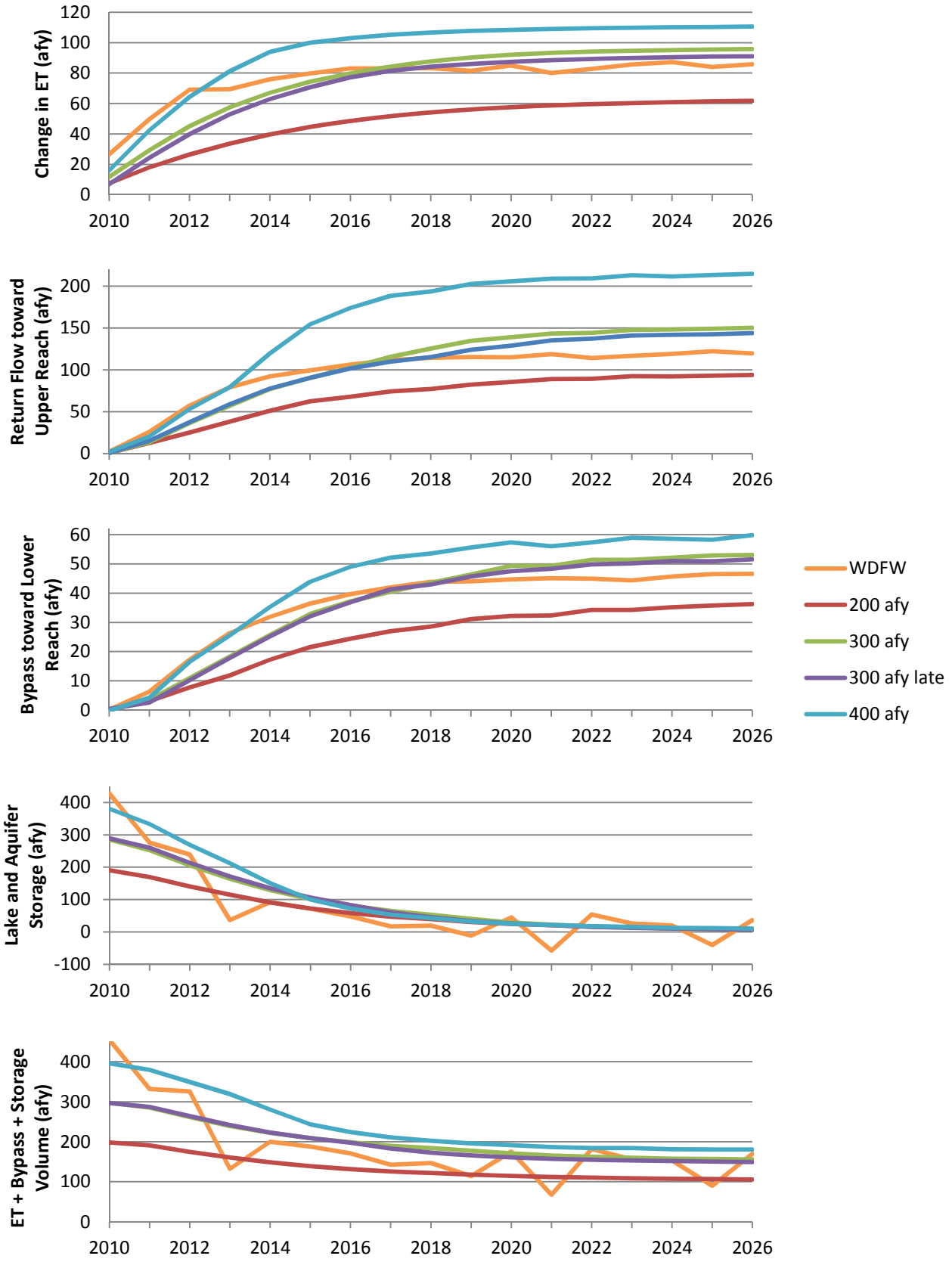

Notes: Values presented are water year totals (October - September).
Values show change relative to existing buildout.

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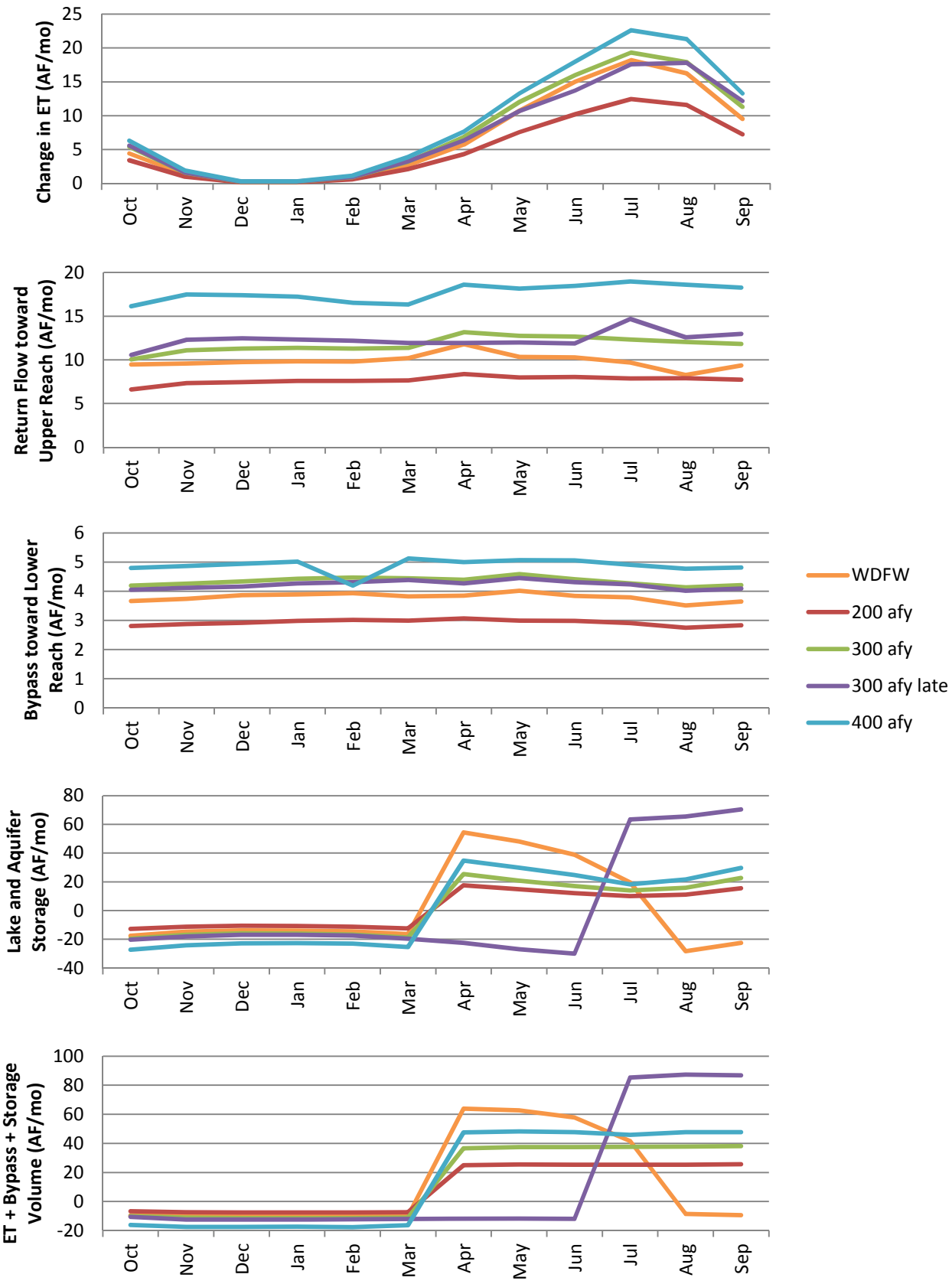
Figure 6
Annual Water Balances
TLAC Water Right Application
Winthrop, Washington



Notes: Values presented are average of last 5 years of model simulation.
Values showing change are relative to existing condition.

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Figure 7
Monthly Water Balances
TLAC Water Right Application
Winthrop, Washington

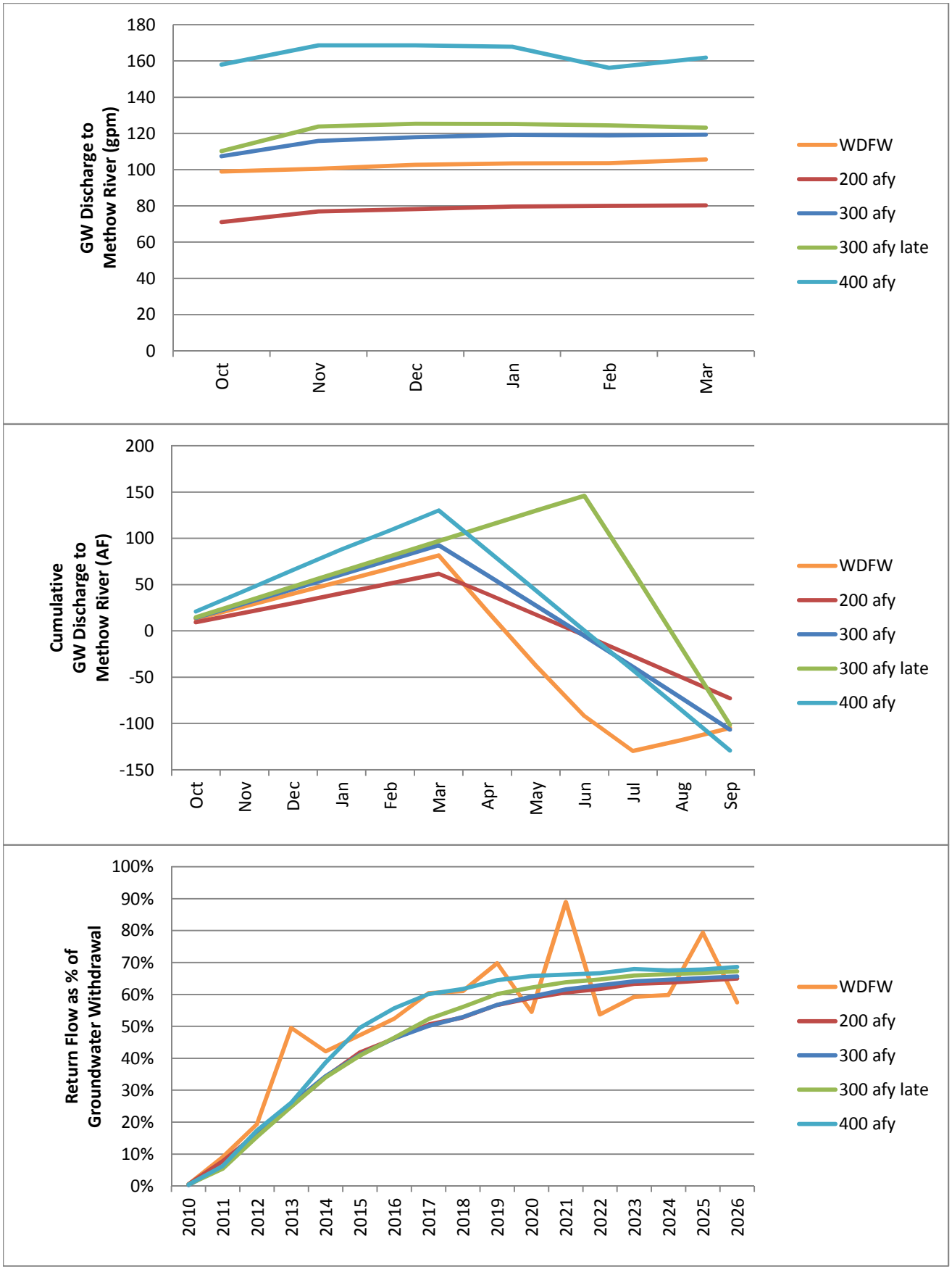

Figure 8

Summary of Total Return Flow to Methow River

TLAC Water Right Application

Winthrop, Washington

Aspect Consulting, LLC

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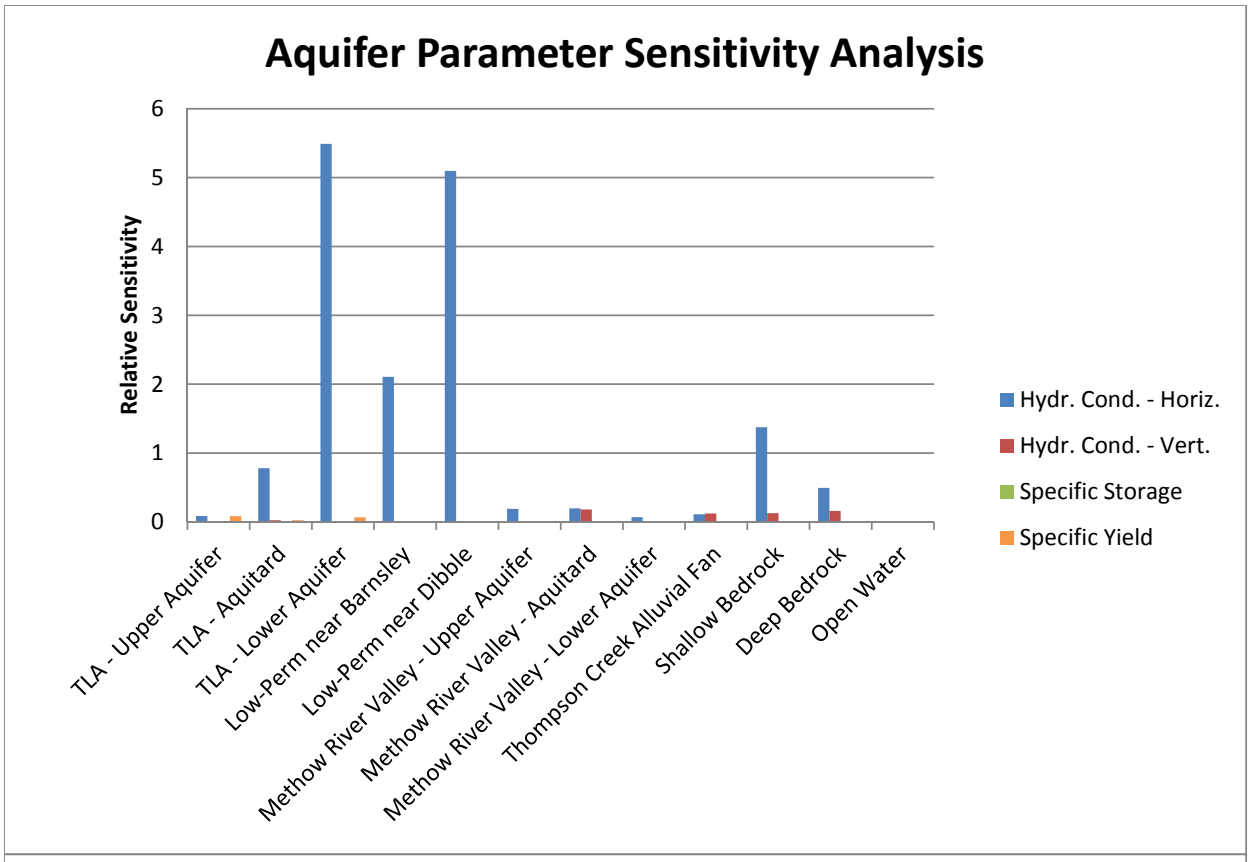

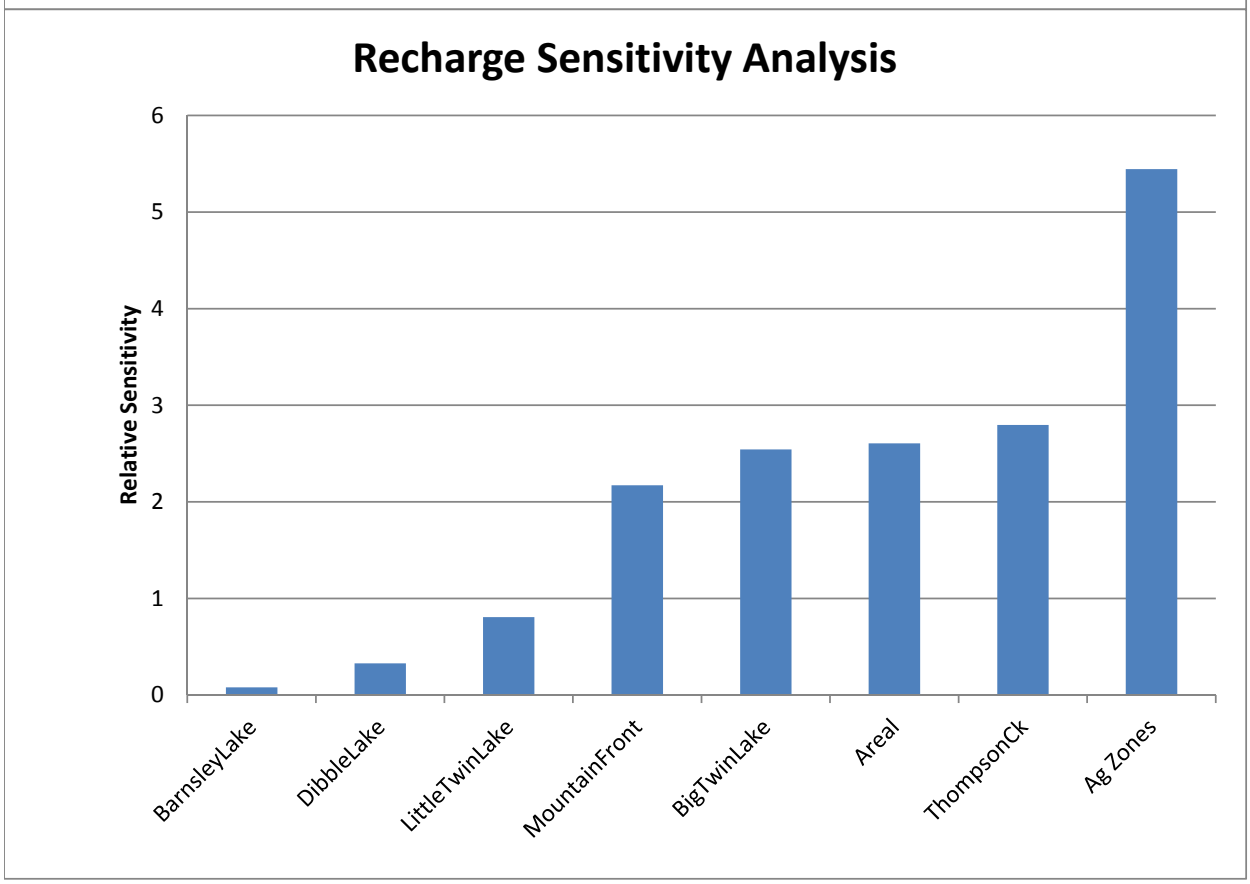

Figure 9
Model Parameter Sensitivity Analysis Results
TLAC Water Right Application
Winthrop, Washington

ATTACHMENT A

Infiltration Only Scenario

A. Infiltration Only Scenario

A meeting was held with TLAC and Ecology to discuss results of the draft memorandum. During that meeting, TLAC indicated that an infiltration-only scenario (InfOnly) should also be developed. Under this scenario, infiltration was introduced at a location specified by TLAC between Big Twin and Barnsley Lakes. The modeled scenario assumed 400 afy of water was available under the same constraints as the 400 afy scenario.

Lake level fluctuations are shown on Figure A-1 with other scenarios for comparison. The InfOnly model run predicts a 4- to 5-foot rise in water levels in Big Twin Lake compared to the existing buildout scenario; however, water levels are about 1 to 2 feet lower than the target lake level elevations. Barnsley Lake levels also show a 4- to 5-foot water level rise and achieves the target lake level in about year 3, but fluctuates about 2 feet annually.

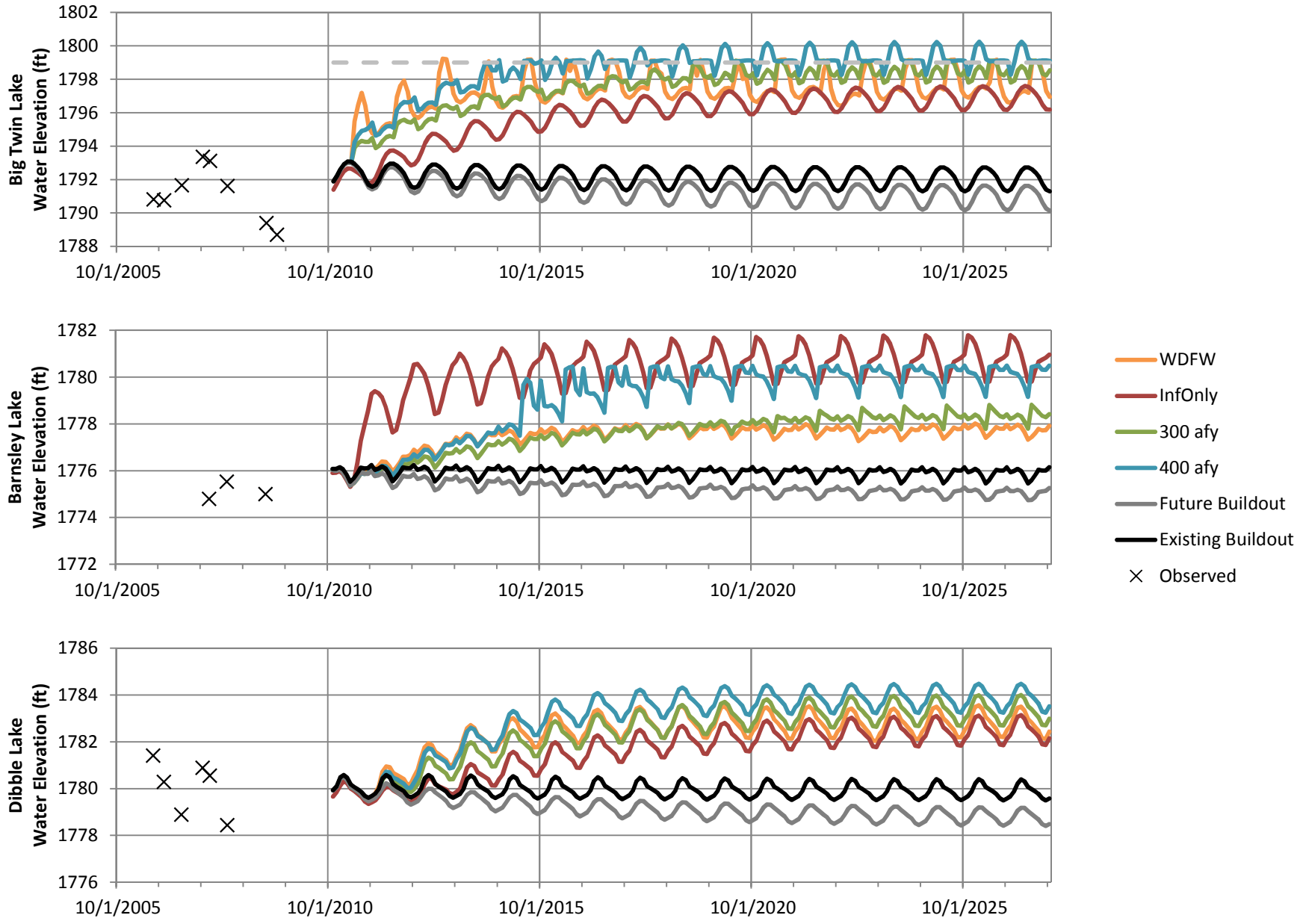

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Figure A-1: Observed and Calculated Lake Levels
TLAC Water Right Application
Winthrop, Washington

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