US Army Corps
of Engineers
Portland District

# Willamette Basin Review Feasibility Study

## APPENDIX D

## Flow Dataset Used for ResSim Analyses

June 2018

# Appendix D
# Willamette Basin Review – Flow Dataset Used for ResSim Analyses

This report documents the flow dataset used for the Willamette Basin Review (WBR) Feasibility study HEC-ResSim model analyses. The flow dataset covers the headwater reservoir inflows (Hills Creek, Fall Creek, Cottage Grove, Dorena, Fern Ridge, Cougar, Blue River, Green Peter, and Detroit), local inflows to downstream reservoirs in series (Foster and Lookout Point), and the local flows on tributaries or the mainstem that are downstream of all reservoirs.

The "*2010 Level Modified Streamflows*" [BPA, 2011] is the report documenting the development of the flow dataset and the flows are found in the HEC-DSS file called *2010_modified.dss*. The flow dataset was developed jointly by the Bonneville Power Administration (BPA), the US Army Corps of Engineers (USACE), and the Bureau of Reclamation (BOR) for the whole Columbia Basin. The dataset covers late 1928 through most of 2008, with 79 continuous, full calendar years of flow data.

This report describes some of the basics about the flow dataset, why this dataset was chosen for the WBR study, what some of the specific assumptions were for the Willamette Basin, and describes the slight modifications made to a few of the flow records for use with the WBR study.

## Contents

# 1 Introduction

The Willamette Basin Review (WBR) Feasibility Study requires a set of reservoir regulation analyses to determine the system behavior under a variety of alternatives. These alternatives represent different demands on the water supply in the Willamette Basin for approximately the year 2050, with each alternative result compared to a baseline analysis. The demands for the alternatives include municipal and industrial uses (M&I), irrigation, and fish and wildlife flow targets, with the baseline analysis representing the current demand levels and the alternatives representing possible 2050 demand levels. The reservoir regulation analyses will quantify the possible changes to reservoir operations for each alternative, and determine the impact to meeting flow targets and any impacts to recreation and hydropower that the new demands may have on the system in order to determine the feasibility of re-allocating some of the reservoir storage in the basin.

The flow dataset commonly referred to as "*the 2010 Level Modified Flows*" [BPA, 2011] was chosen for the analyses for the WBR project, both for the baseline analysis and all alternative analyses. This dataset was developed jointly by three federal agencies (BPA, USACE, and the BOR) and builds on datasets developed roughly every decade for the whole Columbia Basin. The goal behind the development of the modified flows, which is updated and increased in size every ten years, is to have a consistent and accepted regional streamflow dataset that can be used by federal agencies, hydropower planners, fishery agencies and organizations, universities, research organizations, contractors and public interest groups. Roughly every ten years, another decade of flows are added to the dataset, and all years in the dataset are adjusted to represent the current levels of irrigation depletions.

The dataset spans September 1928 to October 2008 with daily average flow values. The current level of irrigation in the 2010 modified flows is defined from the year 2008, which is the last year of the dataset. The adjustment includes estimates for evaporation and return flows as well.

*To summarize this flow set, the modified flows are defined as the historical streamflows that would have been observed without reservoir regulation and with all years adjusted to the same level of irrigation depletions (2008) so that changes in irrigation practices have been accounted for across all years of the dataset.*

The 2010 Modified Flow dataset development is fully documented in the report "2010 Level Modified Streamflows", BPA 2011. The specifics of that dataset development will not be repeated in this report, but several particulars of that development will be highlighted here for a better understanding of the flow dataset used for the WBR study. These specifics are presented in Section 2. The use of these flow records in the reservoir regulation analyses for the WBR is discussed in Section 3, in particular some differences in the flow dataset for Willamette Basin modeling and the 2010 Modified Flow dataset. Section 4 contains a summary of the depletion calculations for the Willamette that are in the 2010 Modified Flow report so that the adjustments that will need to be made for the changing demands in the WBR Feasibility Study are documented. Section 5 contains some additional discussion about irrigation diversion and depletion data used in the flow set, describing how future demand adjustments will be calculated for the alternatives in the WBR report.

# 2 The 2010 Modified Flow Records

The full flow dataset for the 2010 Modified Flows are in a DSS[1] file with 567 time series records and a file size of about 82.5 megabytes. A DSS file is viewed in the program HEC-DSSVue, which displays each time series record in the file with a six-part name. The part names are listed in six columns and labeled Part A through Part F, with Part D always representing the time range of the data and Part E always indicating the time step unit of the data. Each time series record is also given a record number. The image below in Figure 2.1 is from viewing the 2010 Modified Flow file in DSSVue. The data shown in the figure has been sorted alphabetically by Part A and shows only the first 17 records.

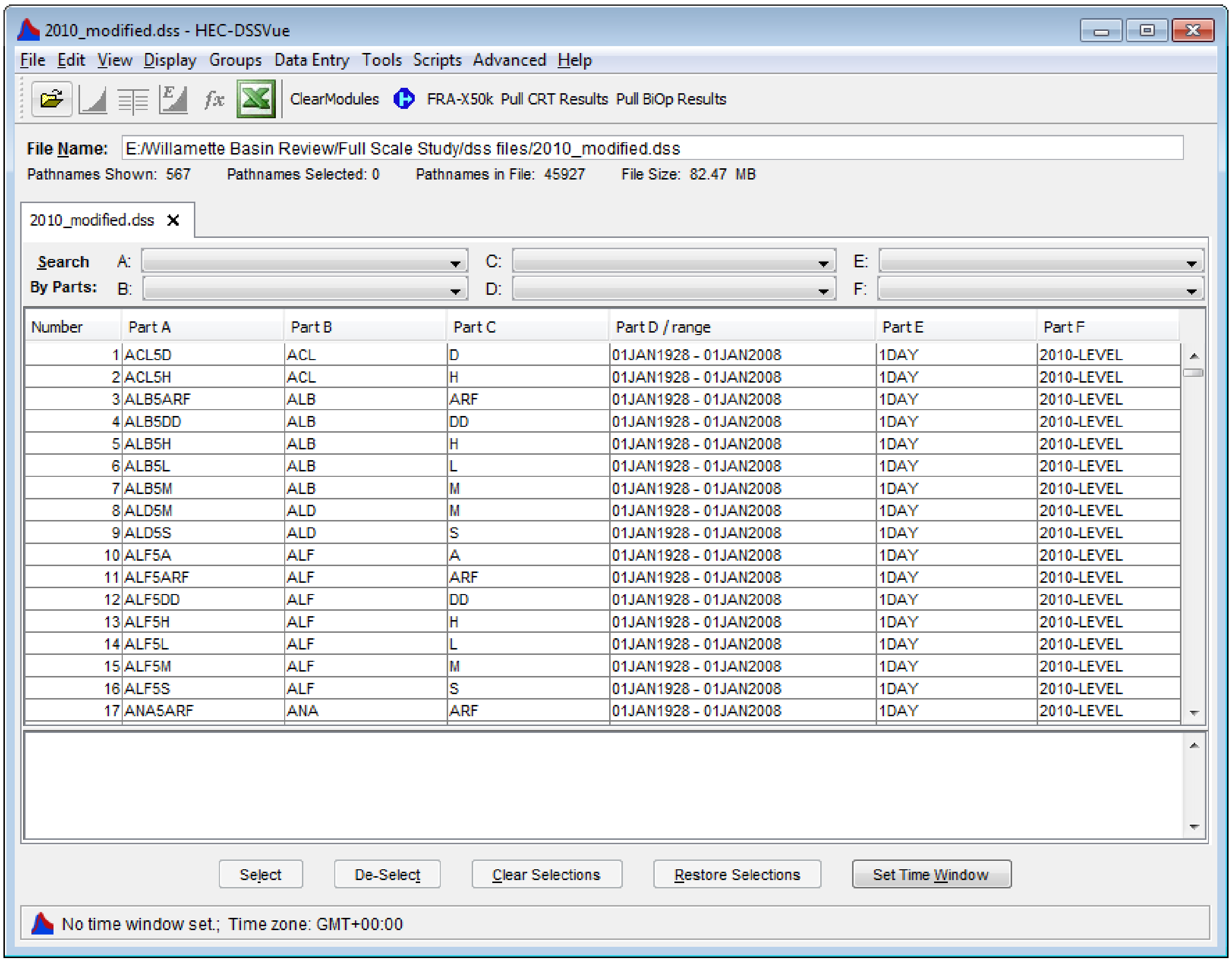


***Figure 2.1 Image of the 2010 Modified Flow file from DSSVue.***

This section will focus on some of the descriptions of the time series records within the 2010 Modified Flow file so that those records chosen for use in the reservoir regulation analyses for the WBR study are documented.

[1] DSS stands for "Data Storage System", which is a database system designed by the U. S. Army Corps of Engineers Hydrologic Engineering Center. These database files may be viewed in the program HEC-DSSVue.

The Part A names of the time series records all use a three letter code that denotes a specific location, then the number "5" since this was the fifth modified flow dataset developed, and then another one to three letters denoting a data type.

The Part B name is always the three letter location code. Since the full dataset includes locations throughout the Columbia Basin, most of the time series records in the DSS file will not be relevant to the WBR study. The locations specific to the Willamette Basin are listed in Table 3-10, page 70, of the 2010 Modified Flow report, along with a notation for which data types are included at each location. See Figure 2.2 for an image of that report table. (This report contains numerous figures which are images from the 2010 Modified Flow report – these images will all contain that report's table or appendix number and will be shadowed in yellow, as in the figure below.)

**Table 3-10. Willamette Basin Points**

| id | name | basin | H | S | A | L | ARF | D | DD | E | EE | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HCR | Hills Creek | Willamette | x | x | x | | | | | | | x |
| LOP | Lookout Point | Willamette | x | x | x | | x | | | x | | x |
| DEX | Dexter | Willamette | | | | | | | | | | x |
| FAL | Falls Creek | Willamette | x | x | x | | | | | | | x |
| COT | Cottage Grove | Willamette | x | x | x | | | | | | | x |
| DOR | Dorena | Willamette | x | x | x | | | | | | | x |
| CAR | Carmen Diversion | Willamette | x | | | | | | | | | x |
| SMH | Smith R. Reservoir | Willamette | | | x | | | | | | | x |
| C_S | Carmen-Smith PP inflow | Willamette | | | x | | | | | | | x |
| TRB | Trail Bridge | Willamette | x | | | x | x | | | | | x |
| CGR | Cougar | Willamette | x | x | x | | | | | | | x |
| BLU | Blue River | Willamette | x | x | x | | | | | | | x |
| LEA | Leaburg | Willamette | x | | x | x | x | | | | | x |
| WAV | Walterville | Willamette | x | | x | x | x | | | | | x |
| FRN | Fern Ridge | Willamette | x | x | x | | | x | | x | | x |
| ALB | Albany | Willamette | x | | | x | x | | x | | | x |
| DET | Detroit | Willamette | x | x | x | | | | | | | x |
| BCL | Big Cliff | Willamette | x | | | | x | | | | | x |
| GPR | Green Peter | Willamette | x | x | x | | | | | | | x |
| FOS | Foster | Willamette | x | x | x | x | x | | | | | x |
| SLM | Salem | Willamette | x | | | x | x | | x | | | x |
| SVN | T.W. Sullivan | Willamette | x | | | x | x | | x | | x | x |
| TMY | Timothy Meadows | Willamette | x | x | x | | | | | | | x |
| OAK | Oak Grove | Willamette | x | | x | | | | | | | x |
| NFK | North Fork | Willamette | x | x | x | | | | | | | x |
| FAR | Faraday | Willamette | | | | | | | | | | x |
| RML | River Mill | Willamette | | | | | | | | | | x |
| HYD | Carmen Div. Max 630 cfs | Willamette | | | x | | | | | | | |
| WMT | Willamette | Willamette | | | | | | x | | | | |

***Figure 2.2 Image of Willamette Basin List of Points from Table 3-10 in the 2010 Modified Flow report.***

The Part C name of each DSS record is the data type, which are defined in Figure 2.3 below from an image of Table 1-2 from the Modified Flow report. Each of the locations shown in Figure 2.2 has an “X” in the data type column if that record was part of the flow dataset. Note that the Part A names shown in Figure 2.1 are the Part B location, “5”, and then the data type from Figure 2.2.

**Table 1-2. Data Types**

| ID | Data Types |
|---|---|
| *H* | Average daily observed streamflow or project outflow, cfs |
| *S* | Average daily observed storage change at projects, cfs (This includes storage change during initial fill of the projects) |
| *A* | Average daily inflow into projects - either provided by the project owners or calculated as: Inflow (A) = Outflow (H) + Storage Change (S), cfs |
| *L* | Average daily local flow (incremental flow between adjacent stations or projects), cfs |
| *P* | Average daily diversion to Banks Lake from Franklin Delano Roosevelt Lake (FDR) (via pumping), cfs |
| *G* | Average daily diversion from Banks Lake to Franklin Delano Roosevelt Lake (FDR) (for generation), cfs |
| *ARF* | Average daily unregulated flow based on Streamflow Synthesis and Reservoir Regulation (SSARR) routing, cfs |
| *E* | At site evaporation, cfs |
| *D* | At site irrigation depletion, cfs |
| *EE* | Accumulated evaporation for all upstream points, cfs |
| *DD* | Accumulated depletions for all upstream points, cfs |
| *M* | Average daily modified flow, cfs |
| *R* | Monthly regulated flow provided by the Bureau of Reclamation, cfs (referred to as "Modified flows" in Bureau's technical report in Section 4) |

***Figure 2.3 Image of data type definitions from Table 1-2 of the 2010 Modified Flow report.***

Several of the data types in Figure 2.3 are worth a separate discussion in this report so that their use in the WBR analyses is documented. The “M”, “L”, “D and DD”, and “E and EE” are discussed below.

The data type that is used the most in the WBR analyses is the “M” data. These records are the modified flows, or the final product after all adjustments, and can be defined more fully than in Figure 2.3 as:

- “M” data types are total daily average flow values and are considered the modified flows. These types of flows are used as headwater reservoir inflows in the reservoir regulation analyses and as total flow values at specific locations in the basin. Data types “M” have had all adjustments accounted for. For example, time series record “SLM5M” is the unregulated flow at Salem with depletion adjustments in the DSS record set.
- The reservoir regulation analyses for the WBR will use the “5M” time series records for all USACE headwater reservoir inflows, which are Hills Creek (HCR5M), Fall Creek (FAL5M), Cottage Grove (COT5M), Dorena (DOR5M), Fern Ridge (FRN5M), Cougar (CGR5M), Blue River (BLU5M), Green Peter (GPR5M), and Detroit (DET5M).

Another data type of importance to the Willamette reservoir regulation analyses is:

- "L" data types are average daily local flows, which are incremental flows between adjacent stations or projects. These types of flows are needed in the analyses at locations downstream of the dams so that all the water in the system is accounted for. Data types "L" have had depletion adjustments. These flow records must be studied carefully to make sure that the flows included in the calculation are clearly understood. For example, the local flow record at Albany, ALB5L, does ***not*** include McKenzie River flows above Walterville and downstream of the Blue River and Cougar Dams, but does include all of the flows coming into the Willamette River downstream of the USACE dams on the Middle Fork and Coast Fork Willamette Rivers and the Long Tom River. In order to include all the water in the system at Albany, all flows on the McKenzie River must be included, so the local flows at Walterville and Leaburg and the total flow at Trial Bridge are input to the ResSim model along with ALB5L.

The following data types are adjustments that have already been included in the "L" and "M" data where appropriate, but the records are available to document the adjustments:

- "D" data types which are at site irrigation depletions. This data is an incremental depletion that accounts for the depletion per unit area and the incremental irrigated acres. This adjustment accounts for changes in irrigation demand and application methods. This incremental depletion is an estimate of the differences between the actual depletion for a given year and the estimated depletion at 2008 levels. See pages 12 and 13 of the Modified Flow report for more on this data. In the Willamette Basin, there are two locations for incremental depletion calculations, which are at Fern Ridge (FRN) and an area called "Willamette" (WMT). These two areas are defined below in Figure 2.4 with an image from the Modified Flow report. The Appendix D of the 2010 Modified Flow report contains many tables of data for these two areas. In Appendix C of the Modified Flow report, it is also clarified that the depletion is the sum of the diversion and the return flow. (See page C-22 of that report.)
- "DD" data types are accumulated depletions for all upstream points. This is because the incremental depletions carry downstream from subarea to subarea, and the DD data accounts for the net effect of all upstream incremental depletions. In the Willamette Basin, Albany (where there is a DD record) has accumulated incremental depletions from Fern Ridge and 25% of the incremental depletion for the Willamette "WMT" area. (See Figure 2.4 below.) Salem has accumulated depletions as well, which is for 15% of the incremental depletion calculated for the WMT area. The rest of the incremental depletion in the WMT area, 53%, is applied at T.W. Sullivan (SVN) as shown in Figure 2.4.
- "E" data types which are at site evaporation values.
- "EE" data types which are accumulated evaporation values for all upstream points.

Note that since evaporation has already been accounted for, the reservoir regulation analyses for the WBR study should not include any estimate of evaporation in the physical parameter specifications of each reservoir.

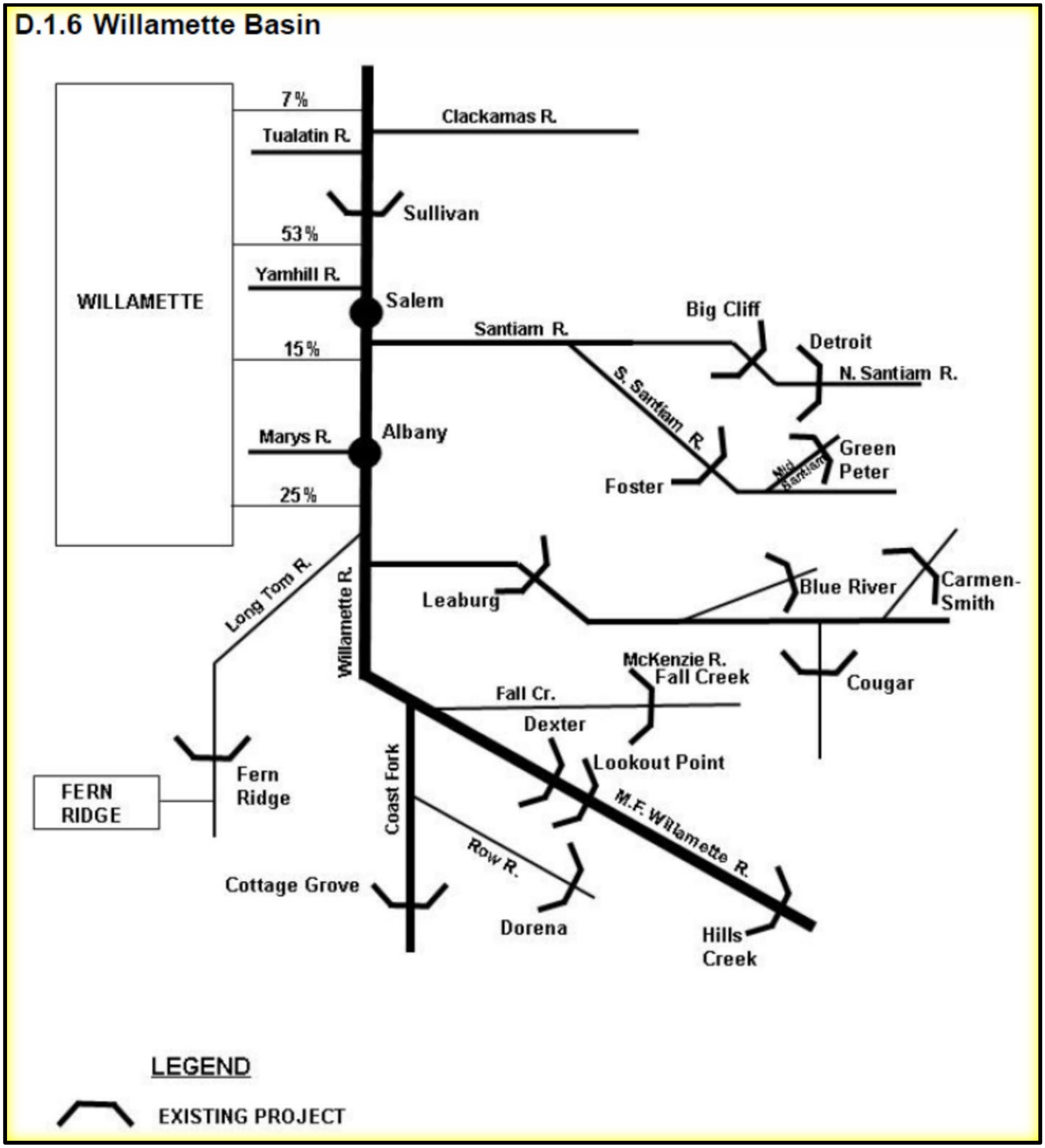


***Figure 2.4 Image of the Willamette Basin incremental depletion areas from Appendix D.1.6 of the 2010 Modified Flow report.***

# 3 Use of the 2010 Modified Flows in the Willamette Basin Analyses

The reservoir regulation analyses for the WBR Feasibility study use the HEC program ResSim. The program inputs are river reach routings, reservoir physical parameter specifications, rules written in operation sets at the reservoirs, and flow datasets. This report documents the flow dataset used in the ResSim analyses for the WBR study, and the Model Documentation Report [USACE, 2016] covers the remaining inputs needed for the ResSim analyses.

The location list shown in Figure 2.2, an image of the Willamette points available in the 2010 Modified Flow report, contains some locations that are not needed for the reservoir regulation analysis and some locations that require slight adjustments before using for ResSim inputs. The list for Figure 2.2 is repeated again in Figure 3.1 below, with red circles identifying which time series records are used as-is and with blue circles identifying locations where local flows had to be slightly adjusted to match total flows. Figure 3.2 compliments Figure 3.1, with Figure 3.2 an image from the 2010 Modified Flow report showing the dams included in the full modified flow report and annotated to denote some particulars about Willamette Basin modeling. The two locations with blue circles in Figure 3.1, Lookout Point and Foster, are annotated in light green in Figure 3.2 indicating that local flows needed some adjustments. Note that there are more locations listed in Figure 3.1 than dams shown in Figure 3.2, because the basin locations include local flow points as well as dams.

The goal of defining the flow input dataset to use in the reservoir regulation analyses is to capture the total volume of water in the Willamette Basin, down to Oregon City above the Willamette Falls, where the small dam called T. W. Sullivan is located. Sullivan is a small hydropower project that is not owned or operated by the Corps and there are no reservoir operations specified for Sullivan in the ResSim model, but its location exists as the lowest downstream point in the watershed used for WBR analyses.

The first annotation to note in Figure 3.2 is that the dams shown to the right of Sullivan and circled in black, are downstream of the model watershed and so have no flow inputs to the WBR ResSim model. Those dams are on the Clackamas River, which joins the Willamette River downstream of Willamette Falls, outside the model area for the WBR. This is why there are no flow inputs used for RML (River Mill), FAR (Faraday), NFK (North Fork), OAK (Oak Grove), or TMY (Timothy Meadows).

The second thing to note about the Figure 3.2 annotations is that the re-regulation dams Big Cliff and Dexter (BCL and DEX, respectively), do not need flow inputs in the ResSim model. Big Cliff is just downstream of Detroit dam and on a day average passes all water flowing from Detroit – it has little storage of its own and is not counted in the total conservation storage available in the Willamette projects. Big Cliff reservoir does not have a rule curve it follows – it does not fill in the conservation season and draft for winter flood control, it just fluctuates a small amount during a day to even the flow out of Detroit. Dexter dam, just downstream of Lookout Point, operates in the same way. Therefore, these two projects do not contain operation sets in the ResSim model and their local flows are captured at Detroit and Lookout Point. These two locations do not show a red or blue circle in Figure 3.1 for this reason, and are highlighted in yellow boxes in Figure 3.2.

The McKenzie River has some non-Corps dams both downstream of both Blue River and Cougar dams and upstream of them as well. These are very small projects without flood control space or conservation storage, and the Corps does not include these dams in ResSim models of the Willamette Basin. However, because the 2010 Modified Flow dataset breaks these dams out, some of the flows must be accounted for to capture the total volume of water in the basin. The total flow at Trail Bridge (TRL5M) is used, which also includes water from Carmen and Smith River (CAR, SMH, and C_S), and downstream of Blue River and Cougar, the local flows at Leaburg (LEA) and Walterville (WAV) are used as inflow locations in the ResSim model. LEA and WAV are annotated in Figure 3.2 with the rust colored circle and Trail Bridge and the projects above it are annotated by light blue circles.

The remaining annotations in Figure 3.2 are for Foster and Lookout Point, highlighted in light green boxes in the figure and shown with blue circles in Figure 3.1. Ideally, the local flows at Foster (FOS5L) and at Lookout Point (LOP5ARF) would be used, but the calculation of these two records in the 2010 Modified Flow dataset included some assumptions about upstream dam operations that are different than the operation sets used in the ResSim model. Therefore, those local flows need to be adjusted slightly so the total water passing through Foster and Lookout Point matches the FOS5M and LOP5M records.

The 2010 Modified Flow record for LOP5ARF was calculated by routing estimated historical streamflows from Hills Creek to Lookout Point (LOP) and using observed changes in project storage values at LOP and Dexter (DEX) to back out the effects of reservoir regulation at LOP. FOS5L was calculated in a similar manner, but routing from Green Peter (GPR) to FOS was neglected. More accurate storage elevation tables are used in the Willamette HEC-ResSim model (1 foot elevation steps) than in the Modified Flow set development (10 foot elevation steps), and routing improvements were made. The methodology for the development of local flows at FOS and LOP for use with the 2010 Modified Flows applies the upstream project 5M inflows to Hills Creek and Green Peter, routes these flows through Lookout Point and Foster with no reservoir regulation, and then takes the difference between the cumulative flow values of LOP5M and FOS5M from the routed outflows at Lookout Point and Foster to obtain a hybrid local inflow that produces the correct total flow at LOP and FOS. A summary of the creation of these two hybrid local flows is:

- Adjust the local flow at Foster so that the total unregulated flow out of Foster is equal to the Foster total flow FOS5M from the 2010 Modified Flow dataset.
- Adjust the local flow at Lookout Point so that the total unregulated flow out of Lookout Point is equal to the Lookout Point total flow LOP5M from the 2010 Modified Flow dataset.

This process of creating hybrid local flows at Foster and Lookout Point ensures that the water volume total in the basin stays the same as in the 2010 Modified Flows dataset.

## 3.7.2 List of Points

**Table 3-10. Willamette Basin Points**

| id | name | basin | H | S | A | L | ARF | D | DD | E | EE | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HCR | Hills Creek | Willamette | x | x | x | | | | | | | x |
| LOP | Lookout Point | Willamette | x | x | x | | x | | | x | | x |
| DEX | Dexter | Willamette | | | | | | | | | | x |
| FAL | Falls Creek | Willamette | x | x | x | | | | | | | x |
| COT | Cottage Grove | Willamette | x | x | x | | | | | | | x |
| DOR | Dorena | Willamette | x | x | x | | | | | | | x |
| CAR | Carmen Diversion | Willamette | x | | | | | | | | | x |
| SMH | Smith R. Reservoir | Willamette | | | x | | | | | | | x |
| C_S | Carmen-Smith PP inflow | Willamette | | | x | | | | | | | x |
| TRB | Trail Bridge | Willamette | x | | | x | x | | | | | x |
| CGR | Cougar | Willamette | x | x | x | | | | | | | x |
| BLU | Blue River | Willamette | x | x | x | | | | | | | x |
| LEA | Leaburg | Willamette | x | | x | x | x | | | | | x |
| WAV | Walterville | Willamette | x | | x | x | x | | | | | x |
| FRN | Fern Ridge | Willamette | x | x | x | | | x | | x | | x |
| ALB | Albany | Willamette | x | | | x | x | | x | | | x |
| DET | Detroit | Willamette | x | x | x | | | | | | | x |
| BCL | Big Cliff | Willamette | x | | | | x | | | | | x |
| GPR | Green Peter | Willamette | x | x | x | | | | | | | x |
| FOS | Foster | Willamette | x | x | x | x | x | | | | | x |
| SLM | Salem | Willamette | x | | | x | x | | x | | | x |
| SVN | T.W. Sullivan | Willamette | x | | | x | x | | x | | x | x |
| TMY | Timothy Meadows | Willamette | x | x | x | | | | | | | x |
| OAK | Oak Grove | Willamette | x | | x | | | | | | | x |
| NFK | North Fork | Willamette | x | x | x | | | | | | | x |
| FAR | Faraday | Willamette | | | | | | | | | | x |
| RML | River Mill | Willamette | | | | | | | | | | x |
| HYD | Carmen Div. Max 630 cfs | Willamette | | | x | | | | | | | |
| WMT | Willamette | Willamette | | | | | | x | | | | |

Time series Record Used as-is

Hybrid Time series developed using both records

***Figure 3.1 Flow time series records from the 2010 Modified Flows used for modeling Willamette Basin project operations for the WBR study.***

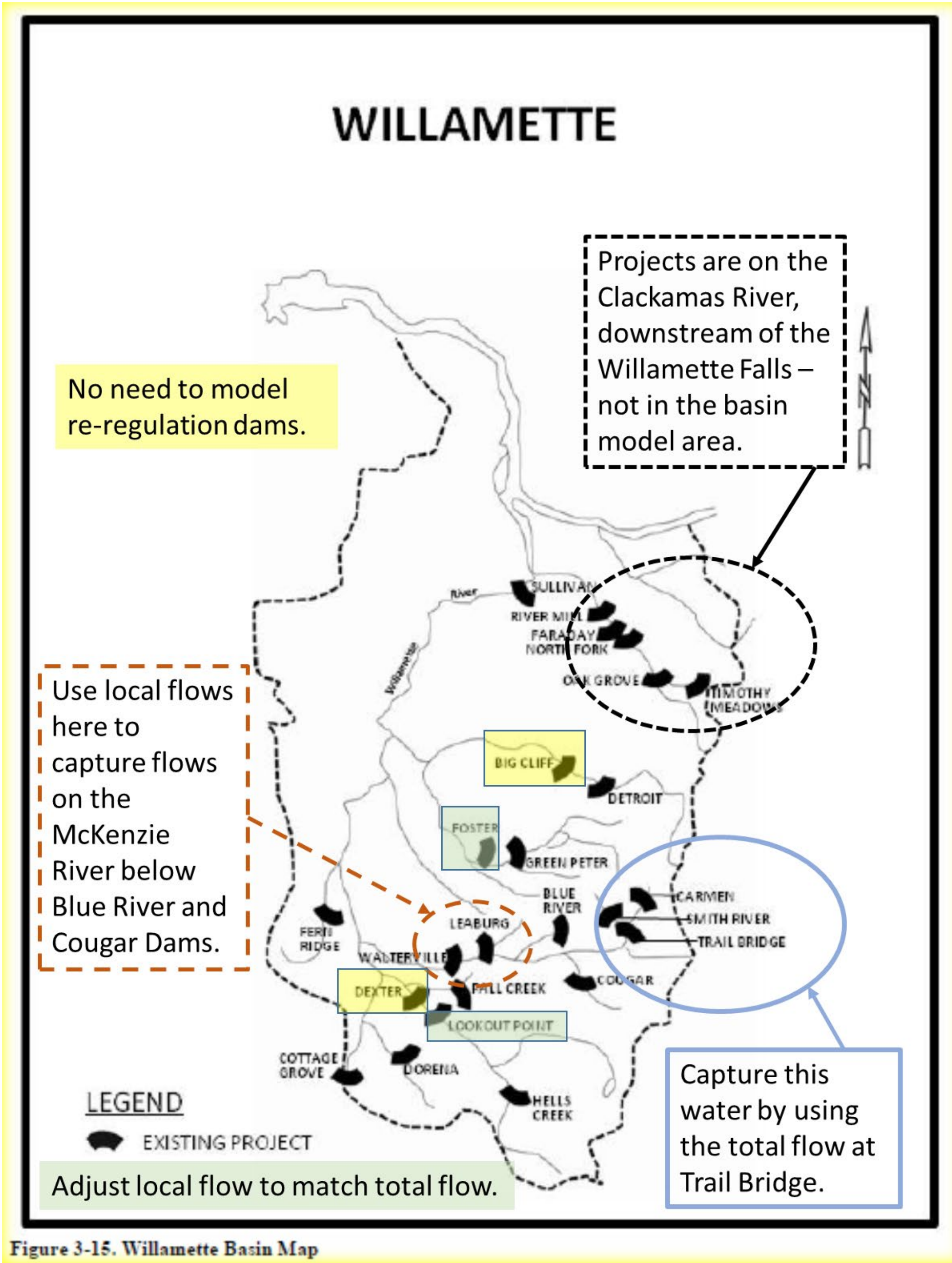


***Figure 3.2 Image of the Willamette Basin projects from Figure 3-15 of the 2010 Modified Flow report, annotated with flow dataset notes for the WBR study.***

# 4 Willamette Basin Depletion Calculations in the 2010 Modified Flow Report and Adjustments to use for the WBR Study

Appendix C of the 2010 Modified Flow report contains some detailed descriptions of the incremental irrigation depletions used in the development of the flow dataset. Depletion values were calculated as flow per unit area (cfs per 1000 acres) and by irrigation method (sprinkler or gravity application), calculated on a monthly time step by crop type, and include diversions and return flows. Diversions calculated are a negative value denoting water removed from the system, which occur April through October, and return flows are positive values denoting water unused by crops which is returned to the system throughout the year. (See Page C-1 of the 2010 Modified Flow report.) Depletion values in cfs per 1000 acres are then multiplied by the incremental irrigated acreage to produce depletions in cfs. All calculations for depletions are made for subareas, and then monthly values are converted to daily flow values.

This section outlines the approach to the Willamette Basin depletion calculations in the 2010 Modified Flow report and uses the terminology from that report as well. Note that other Willamette Basin Review reports estimating future demand values may use a different terminology than is presented here, and the approach taken for other WBR demand analyses may follow a different set of steps than what was used for the modified flows. The purpose in summarizing and explaining the depletion calculations for the Willamette Basin in the 2010 Modified Flow work is two-fold: to document how all years are corrected back to the same level of irrigation and to show what level of irrigation demand is represented in the baseline analysis. When the future demand estimates for the WBR alternatives are finalized, it will be the difference between that future demand and the irrigation demands outlined here that will be modeled in ResSim, since the current levels of irrigation demand are inherently included in the baseline analysis.

The approach to the depletion calculations for the Willamette Basin in the 2010 Modified Flow report is summarized as following steps:

1. Define subareas of each sub-basin within the Columbia Basin and perform any subarea partitioning.
2. Calculate the irrigated acres in each subarea.
3. Determine the crop water requirement in each subarea.
4. Describe the irrigation methods and efficiency in each subarea.
5. Determine the diversion per unit area within each subarea.
6. Determine the return flow per unit area within each subarea.
7. Determine the depletions per unit area within each subarea.
8. Determine the incremental irrigation acreage within each subarea.
9. Determine the incremental depletions in cfs for each subarea.
10. Apply the depletion D to modified flow points in each subarea.

The Appendix C of the 2010 Modified Flow report works out one sub-basin in detail for each of the steps outlined above, and then provides the specific data for each sub-basin and subarea in Appendix D. The Willamette specifics from that report are presented here for each step defined above.

**Step 1.**

The Willamette Basin is a sub-basin of its own within the Columbia Basin, and it has two subareas for depletion calculations. The subareas of the Willamette sub-basin are shown in Appendix D.1.6 of the 2010 Modified Flow report and this schematic was shown in Figure 2.4 of this report. The two subareas are Fern Ridge and Willamette. Fern Ridge is broken out separately from the Willamette, but is still considered part of the Willamette. (See Table C-1 in the 2010 Modified Flow report, where the Willamette is listed as Subarea 38, and Fern Ridge as part of subarea 38.)

**Step 2.**

The irrigated acres for the Willamette and Fern Ridge subareas are shown in Appendix D.2.6 in the 2010 Modified Flow report. An image of the data from this report is shown below in Figure 4.1. The Fern Ridge subarea is all part of Lane County, and the Willamette subarea is broken out by 12 counties. The Lane County data for Fern Ridge is included in the county list in the Willamette as well (upper table of Figure 4.1).

The scaling factor, shown at the bottom of the table in Figure 4.1, is used to account for the miscellaneous crop types that are not broken out separately to ensure that all irrigated acreage is accounted for. This scaling factor is then used to scale up the individual crop acreages.

The irrigated acres are then broken out further into the percent of county irrigated acreage within the subarea and the percent distribution of crop types. These are in Appendix D.3.6 of the 2010 Modified Flow report, an image of which is shown below in Figure 4.2.

As an example of this process, see the Willamette subarea, corn for silage data for Benton County from Figures 4.1 and 4.2:

- Acreage value is 238 acres.
- Scaled up acreage value is 238/0.37 = 643 acres. (Note that Figure 4.2 value is 650, so the 37% scaling factor shown for Benton County has been rounded off, and is really 36.6%.)
- The total irrigated cropland in Benton County (higher of USDA or USGS values) is 21,683 acres, of which 650 acres (after scaling without rounding off) is for corn for silage.
- Since Benton County is 100% within the subarea Willamette, the irrigated land for corn for silage is 650*1.0 = 650 acres.
- The acres in the Willamette subarea, all counties, with corn for silage, 27,716 acres. This means 10.1% of the irrigated area in the subarea is for corn for silage.

## D.2.6 Willamette Basin

### Willamette (WMT)

| | | Acres | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | State | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon |
| | County | Benton | Clackamas | Columbia | Douglas | Lane | Lincoln | Linn | Marion | Multnomah | Polk | Washington | Yamhill |
| USDA Table 10 | Irrigated Pastureland | 1,591 | 3,649 | 855 | 6,045 | 3,404 | 302 | 4,914 | 3,565 | 326 | 1,113 | 1,125 | 1,919 |
| USDA Table 25 | Barley | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 148 | 0 |
| | Corn for Grain | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 91 | 0 |
| | Corn for Silage | 238 | 152 | 0 | 0 | 890 | 0 | 1,370 | 3,512 | 0 | 2,269 | 1,511 | 1,099 |
| | Dry Beans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Alfalfa Hay | 1,753 | 5,020 | 1,050 | 8,637 | 4,868 | 405 | 2,611 | 6,413 | 0 | 1,097 | 1,957 | 2,310 |
| | Oats | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 190 | 0 | 0 | 294 | 0 |
| | Sugar Beet | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Wheat | 0 | 0 | 0 | 0 | 0 | 0 | 1,138 | 555 | 0 | 338 | 816 | 52 |
| | Small Vegetables | 5,596 | 2,719 | 8 | 0 | 1,650 | 16 | 5,418 | 22,237 | 2,145 | 1,503 | 3,398 | 3,250 |
| | Orchards w Cover | 354 | 514 | 13 | 822 | 1,217 | 1 | 1,035 | 2,266 | 26 | 1,352 | 1,058 | 3,019 |
| | Sum of Table 25 | 7,941 | 8,405 | 1,071 | 9,459 | 8,625 | 422 | 11,572 | 35,173 | 2,171 | 6,559 | 9,273 | 9,730 |
| Higher of USDA or USGS | Total Irrigated Cropland | 21,683 | 24,163 | 1,680 | 10,377 | 19,000 | 538 | 27,308 | 92,817 | 6,703 | 15,538 | 25,107 | 24,864 |
| Scaling Factor | Sum of Table 25 / Total Irrigated Cropland = | 37% | 35% | 64% | 91% | 45% | 78% | 42% | 38% | 32% | 42% | 37% | 39% |

### Fern Ridge (FRN)

| | | Acres |
|---|---|---|
| | State | Oregon |
| | County | Lane |
| USDA Table 10 | Irrigated Pastureland | 3,404 |
| USDA Table 25 | Barley | 0 |
| | Corn for Grain | 0 |
| | Corn for Silage | 890 |
| | Dry Beans | 0 |
| | Alfalfa Hay | 4,868 |
| | Oats | 0 |
| | Sugar Beet | 0 |
| | Wheat | 0 |
| | Small Vegetables | 1,650 |
| | Orchards w Cover | 1,217 |
| | Sum of Table 25 | 8,625 |
| Higher of USDA or USGS | Total Irrigated Cropland | 19,000 |
| Scaling Factor | Sum of Table 25 / Total Irrigated Cropland = | 45% |

***Figure 4.1 Image of Appendix D.2.6, the irrigated crop acres for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

## D.3.6 Willamette Basin

### Willamette (WMT)

| | Percentage of counties' irrigated land within subarea. Used to arrive at acreage in next table below. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon |
| County | Benton | Clackamas | Columbia | Douglas | Lane | Lincoln | Linn | Marion | Multnomah | Polk | Washington | Yamhill |
| County Contribution to subarea | 100.0% | 93.8% | 33.3% | 0.1% | 96.0% | 5.6% | 100.0% | 100.0% | 58.9% | 100.0% | 100.0% | 100.0% |

| | Irrigated Acres per county within the subarea. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | Oregon | | |
| County | Benton | Clackamas | Columbia | Douglas | Lane | Lincoln | Linn | Marion | Multnomah | Polk | Washington | Yamhill | Total Acres | Percent |
| Barley | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 401 | 0 | 401 | 0.1% |
| Corn for Grain | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 246 | 0 | 246 | 0.1% |
| Corn for Silage | 650 | 410 | 0 | 0 | 1,881 | 0 | 3,233 | 9,268 | 0 | 5,375 | 4,091 | 2,808 | 27,716 | 10.1% |
| Dry Beans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Alfalfa Hay | 4,787 | 13,531 | 548 | 9 | 10,290 | 29 | 6,162 | 16,923 | 0 | 2,599 | 5,299 | 5,903 | 66,078 | 24.1% |
| Oats | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 501 | 0 | 0 | 796 | 0 | 1,297 | 0.5% |
| Sugar Beet | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Wheat | 0 | 0 | 0 | 0 | 0 | 0 | 2,685 | 1,465 | 0 | 801 | 2,209 | 133 | 7,293 | 2.7% |
| Small Vegetables | 15,280 | 7,329 | 4 | 0 | 3,488 | 1 | 12,786 | 58,681 | 3,899 | 3,561 | 9,200 | 8,305 | 122,534 | 44.7% |
| Orchards w Cover | 967 | 1,385 | 7 | 1 | 2,573 | 0 | 2,442 | 5,980 | 47 | 3,203 | 2,865 | 7,715 | 27,184 | 9.9% |
| Pasture | 1,591 | 3,421 | 284 | 5 | 3,266 | 17 | 4,914 | 3,565 | 192 | 1,113 | 1,125 | 1,919 | 21,413 | 7.8% |

### Fern Ridge (FRN)

| | Percentage of counties' irrigated land within subarea. Used to arrive at acreage in next table below. |
|---|---|
| State | Oregon |
| County | Lane |
| County Contribution to subarea | 27.4% |

| | Irrigated Acres per county within the subarea. | | |
|---|---|---|---|
| State | Oregon | | |
| County | Lane | Total Acres | Percent |
| Barley | 0 | 0 | |
| Corn for Grain | 0 | 0 | |
| Corn for Silage | 537 | 537 | 8.8% |
| Dry Beans | 0 | 0 | |
| Alfalfa Hay | 2,938 | 2,938 | 47.9% |
| Oats | 0 | 0 | |
| Sugar Beet | 0 | 0 | |
| Wheat | 0 | 0 | |
| Small Vegetables | 996 | 996 | 16.2% |
| Orchards w Cover | 735 | 735 | 12.0% |
| Pasture | 933 | 933 | 15.2% |

***Figure 4.2 Image of Appendix D.3.6, the percentage distribution of crop types by county for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

**Step 3.**

The water requirements of the crops in the subareas are determined next, and these requirements are specified per 1000 acres. The data for the Willamette is found in Appendix D.4.6 of the Modified Flow report and Figure 4.3 below shows an image of that data.

## D.4.6 Willamette Basin

### Willamette (WMT)

| | Combined Grains Water Requirement | | Corn for Grain Water Requirement | | Corn for Silage Water Requirement | | Alfalfa Hay Water Requirement | | Small Vegetables Water Requirement | | Orchards w Cover Water Requirement | | Pasture Water Requirement | | Diversion Distribution | Total Water Required by Crops (ac-ft/1000 acres) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland % | 3.3% | | 0.1% | | 10.1% | | 24.1% | | 44.7% | | 9.9% | | 7.8% | | 100.0% | |
| | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | % | |
| JAN | | | | | | | | | | | | | | | | |
| FEB | | | | | | | | | | | | | | | | |
| MAR | | | | | | | | | | | | | | | | |
| APR | 0.52 | 10.2% | | | | | | | | | | | | | 0.3% | 1 |
| MAY | 3.08 | 60.4% | | | | | 2.56 | 11.8% | | | 1.04 | 6.4% | 2.1 | 13.2% | 6.5% | 82 |
| JUN | 1.50 | 29.4% | 1.78 | 11.6% | 1.57 | 10.6% | 4.37 | 20.1% | 1.45 | 12.9% | 4.12 | 25.2% | 3.31 | 20.9% | 16.8% | 215 |
| JUL | | | 5.06 | 33.0% | 4.47 | 30.2% | 6.17 | 28.4% | 4.23 | 37.7% | 5.49 | 33.6% | 4.55 | 28.7% | 32.3% | 394 |
| AUG | | | 5.32 | 34.7% | 5.22 | 35.2% | 5.27 | 24.3% | 3.97 | 35.4% | 4.86 | 29.7% | 4.14 | 26.1% | 30.2% | 365 |
| SEP | | | 3.17 | 20.7% | 3.39 | 22.9% | 3.14 | 14.5% | 1.57 | 14.0% | 0.84 | 5.1% | 1.77 | 11.2% | 13.5% | 169 |
| OCT | | | 0.01 | 0.1% | 0.16 | 1.1% | 0.2 | 0.9% | | | | | | | 0.3% | 5 |
| NOV | | | | | | | | | | | | | | | | |
| DEC | | | | | | | | | | | | | | | | |
| Total | 5.1 | | 15.34 | | 14.81 | | 21.71 | | 11.22 | | 16.35 | | 15.87 | | 100% | 1232 |

### Fern Ridge (FRN)

| | Corn for Silage Water Requirement | | Alfalfa Hay Water Requirement | | Small Vegetables Water Requirement | | Orchards w Cover Water Requirement | | Pasture Water Requirement | | Diversion Distribution | Total Water Required by Crops (ac-ft/1000 acres) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cropland % | 8.8% | | 47.9% | | 16.2% | | 12.0% | | 15.2% | | 100.0% | |
| | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | Inches | % spread over the year | % | |
| JAN | | | | | | | | | | | | |
| FEB | | | | | | | | | | | | |
| MAR | | | | | | | | | | | | |
| APR | | | 0.26 | 1.1% | | | 0.26 | 1.1% | 0.35 | 1.8% | 0.9% | 17 |
| MAY | | | 2.92 | 12.4% | | | 2.93 | 12.4% | 2.28 | 11.8% | 9.2% | 175 |
| JUN | 1.77 | 11.1% | 4.6 | 19.5% | 1.58 | 12.9% | 4.6 | 19.5% | 3.65 | 18.8% | 17.6% | 310 |
| JUL | 4.24 | 26.6% | 6.27 | 26.5% | 4.18 | 34.1% | 6.27 | 26.5% | 5.17 | 26.6% | 27.8% | 466 |
| AUG | 5.32 | 33.4% | 5.56 | 23.5% | 4.24 | 34.6% | 5.56 | 23.5% | 4.7 | 24.2% | 26.3% | 433 |
| SEP | 3.66 | 23.0% | 3.34 | 14.1% | 2.27 | 18.5% | 3.34 | 14.1% | 2.85 | 14.7% | 15.7% | 260 |
| OCT | 0.92 | 5.8% | 0.67 | 2.8% | | | 0.66 | 2.8% | 0.4 | 2.1% | 2.5% | 45 |
| NOV | | | | | | | | | | | | |
| DEC | | | | | | | | | | | | |
| Total | 15.91 | | 23.62 | | 12.27 | | 23.62 | | 19.4 | | 100% | 1705 |

***Figure 4.3 Image of Appendix D.4.6, the crop type water requirements per 1000 acres for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

Using the Willamette combined grains as an example, 5.1 inches of water per 1000 acres are needed from irrigation. Also note that 3.3% of the cropland in WMT is for combined grains.

- Required water is 5.1 inches * (1 ft/12 in) = 0.425 ft.
- Required water volume for combined grains in WMT is 0.425 ft *0.033 * 1000 = 0.014 ac-ft/1000 acres.
- Applying the same methods to the other crop types in the WMT subarea, a total of 1232 ac-ft/1000 acres is calculated. (See last column total value in Figure 4.3.) The value 1232 acres is used in Figure 4.4 below for both irrigation methods for WMT.

- The same method is used in Figure 4.3 to get monthly water requirements by crop and for totals as well.

**Steps 4, 5, and 6.**

The diversion and return flow water volumes per 1000 acres, based on irrigation method efficiencies, is summarized for the Willamette in Appendix D.5.6 of the Modified Flow report and Figure 4.4 below shows an image of that data.

## D.5.6 Willamette Basin

### Willamette (WMT)

| | Sprinkler | Gravity |
|---|---|---|
| Total Volume of Water Required by crops (ac-ft per 1000 ac) | *1232* | *1232* |
| Diversion Efficiency (%) | *76%* | *50%* |
| **Required Diversion (ac-ft per 1000 ac)** | **-1621** | **-2464** |
| Return Efficiency (%) | *20%* | *45%* |
| **Return Flow (ac-ft per 1000 ac)** | **324** | **1109** |

### Fern Ridge (FRN)

| | Sprinkler | Gravity |
|---|---|---|
| Total Volume of Water Required by crops (ac-ft per 1000 ac) | *1705* | *1705* |
| Diversion Efficiency (%) | *76%* | *50%* |
| **Required Diversion (ac-ft per 1000 ac)** | **-2244** | **-3410** |
| Return Efficiency (%) | *20%* | *45%* |
| **Return Flow (ac-ft per 1000 ac)** | **449** | **1535** |

***Figure 4.4 Image of Appendix D.5.6, the irrigation efficiencies and diversion information for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

Using WMT again for an example, the required diversion of ac-ft per 1000 acres for the sprinkler irrigations would be 1232 ac-ft per 1000 acres / 0.76 = 1621 ac-ft per 1000 acres, but the diversion value is negative by definition, so the values in Figure 4.4 are negative for required diversions. The return flow is calculated by the efficiency of the irrigation method, as 1621 ac-ft per 1000 acres * 0.20 = 324 ac-ft per 1000 acres. Return flows are positive by definition.

These volumes of water in the first row of each table above are used to calculate the total flow to be diverted depending on what acreage within a subarea has been irrigated by sprinkler or gravity methods (third row of each table) and the volume of return flow (last row each table). The sprinkler versus gravity method percentages are given later.

**Step 7.**

The depletions per 1000 acres, based on irrigation method efficiencies, is summarized for the Willamette in Appendix D.6.6 of the Modified Flow report and Figure 4.5 below shows an image of that data. This step takes the data from Figure 4.3 and produces the data in Figure 4.5, which is monthly volumes per unit area of diversions, return flows, and depletions (the combined diversion and return flow data.)

## D.6.6 Willamette Basin

### Willamette (WMT)

Sprinkler System

| Month | DIVERSION | | RETURN FLOW | | DEPLETION | |
|---|---|---|---|---|---|---|
| | % | ac-ft per 1000 ac | % | ac-ft per 1000 ac | ac-ft per 1000 ac | cfs per 1000 ac |
| JAN | | | 4.0% | 13 | 13 | **0.2** |
| FEB | | | 4.0% | 13 | 13 | **0.2** |
| MAR | | | 4.0% | 13 | 13 | **0.2** |
| APR | 0.3% | -5 | 4.0% | 13 | 8 | **0.1** |
| MAY | 6.5% | -105 | 5.0% | 16 | -89 | **-1.4** |
| JUN | 16.8% | -272 | 12.0% | 39 | -233 | **-3.9** |
| JUL | 32.3% | -524 | 17.0% | 55 | -469 | **-7.6** |
| AUG | 30.2% | -490 | 18.0% | 58 | -432 | **-7.0** |
| SEP | 13.5% | -218 | 13.0% | 42 | -176 | **-3.0** |
| OCT | 0.3% | -5 | 9.0% | 29 | 24 | **0.4** |
| NOV | | | 6.0% | 19 | 19 | **0.3** |
| DEC | | | 4.0% | 13 | 13 | **0.2** |
| Total = | 100.0% | -1621 | 100.0% | 324 | -1297 | |

Gravity System

| Month | DIVERSION | | RETURN FLOW | | DEPLETION | |
|---|---|---|---|---|---|---|
| | % | ac-ft per 1000 ac | % | ac-ft per 1000 ac | ac-ft per 1000 ac | cfs per 1000 ac |
| JAN | | | 4.0% | 44 | 44 | **0.7** |
| FEB | | | 4.0% | 44 | 44 | **0.8** |
| MAR | | | 4.0% | 44 | 44 | **0.7** |
| APR | 0.3% | -8 | 4.0% | 44 | 36 | **0.6** |
| MAY | 6.5% | -160 | 5.0% | 55 | -104 | **-1.7** |
| JUN | 16.8% | -414 | 12.0% | 133 | -281 | **-4.7** |
| JUL | 32.3% | -797 | 17.0% | 189 | -609 | **-9.9** |
| AUG | 30.2% | -745 | 18.0% | 200 | -546 | **-8.9** |
| SEP | 13.5% | -332 | 13.0% | 144 | -187 | **-3.1** |
| OCT | 0.3% | -8 | 9.0% | 100 | 92 | **1.5** |
| NOV | | | 6.0% | 67 | 67 | **1.1** |
| DEC | | | 4.0% | 44 | 44 | **0.7** |
| Total = | 100.0% | -2464 | 100.0% | 1109 | -1355 | |

### Fern Ridge (FRN)

Sprinkler System

| Month | DIVERSION | | RETURN FLOW | | DEPLETION | |
|---|---|---|---|---|---|---|
| | % | ac-ft per 1000 ac | % | ac-ft per 1000 ac | ac-ft per 1000 ac | cfs per 1000 ac |
| JAN | | | 4.0% | 18 | 18 | **0.3** |
| FEB | | | 4.0% | 18 | 18 | **0.3** |
| MAR | | | 4.0% | 18 | 18 | **0.3** |
| APR | 0.9% | -21 | 4.0% | 18 | -3 | **-0.1** |
| MAY | 9.2% | -206 | 5.0% | 22 | -184 | **-3.0** |
| JUN | 17.6% | -394 | 12.0% | 54 | -340 | **-5.7** |
| JUL | 27.8% | -624 | 17.0% | 76 | -547 | **-8.9** |
| AUG | 26.3% | -590 | 18.0% | 81 | -509 | **-8.3** |
| SEP | 15.7% | -352 | 13.0% | 58 | -294 | **-4.9** |
| OCT | 2.5% | -56 | 9.0% | 40 | -16 | **-0.3** |
| NOV | | | 6.0% | 27 | 27 | **0.5** |
| DEC | | | 4.0% | 18 | 18 | **0.3** |
| Total = | 100.0% | -2244 | 100.0% | 449 | -1795 | |

Gravity System

| Month | DIVERSION | | RETURN FLOW | | DEPLETION | |
|---|---|---|---|---|---|---|
| | % | ac-ft per 1000 ac | % | ac-ft per 1000 ac | ac-ft per 1000 ac | cfs per 1000 ac |
| JAN | | | 4.0% | 61 | 61 | **1.0** |
| FEB | | | 4.0% | 61 | 61 | **1.1** |
| MAR | | | 4.0% | 61 | 61 | **1.0** |
| APR | 0.9% | -32 | 4.0% | 61 | 30 | **0.5** |
| MAY | 9.2% | -313 | 5.0% | 77 | -237 | **-3.8** |
| JUN | 17.6% | -599 | 12.0% | 184 | -415 | **-7.0** |
| JUL | 27.8% | -948 | 17.0% | 261 | -687 | **-11.2** |
| AUG | 26.3% | -897 | 18.0% | 276 | -621 | **-10.1** |
| SEP | 15.7% | -536 | 13.0% | 200 | -336 | **-5.6** |
| OCT | 2.5% | -86 | 9.0% | 138 | 52 | **0.9** |
| NOV | | | 6.0% | 92 | 92 | **1.5** |
| DEC | | | 4.0% | 61 | 61 | **1.0** |
| Total = | 100.0% | -3410 | 100.0% | 1535 | -1876 | |

***Figure 4.5 Image of Appendix D.6.6, the diversion, return flow, and depletions per 1000 acres by month for the irrigation methods for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

The example worked out here again uses the subarea WMT and calculates flow rates per unit acreage for all crops. Using June data from Figure 4.3, to get the second to last column in Figure 4.3 and the first column in Figure 4.5:

- Sum of fraction of each crop type in subarea * fraction of total annual irrigation need (June, WMT),
- = $(0.033 * 0.294)_{\text{combined grains}} + (0.001 * 0.116)_{\text{corn for grain}} + (0.101 * 0.106)_{\text{corn for silage}} + (0.241 * 0.201)_{\text{alfalfa hay}} + (0.447 * 0.129)_{\text{small vegetables}} + (0.099 * 0.252)_{\text{orchards}} + (0.078 * 0.209)_{\text{pasture}} = 0.168$ = 16.8%.
- = volume diverted each June, WMT, per unit area, if sprinklers used= 0.168 *-1621 ac-ft/1000 acres = -272 ac-ft/1000 acres.
- = volume diverted each June, WMT, per unit area, if gravity method used = 0.168 * -2464ac-ft/1000 acres = -414 ac-ft/1000 acres.

The return flows in Figure 4.5 are distributed over the whole year, not just April through October, as irrigation occurs. (See Page C-1 and C-22 of the 2010 Modified Flow report.) The monthly shaping of the return flow percentages in Figure 4.5 are the same for both irrigation methods and for both WMT and FRN. The total return flow volume for each irrigation method and for WMT and FRN, from the last rows of the table in Figure 4.4, are shown as totals in the above Figure 4.5. This total return flow value is then shaped by month according to the monthly percentage shown in Figure 4.5. The return flow volume, in ac-ft per 1000 acres, is found by multiplying the month's percent of the return flow times the total return flow.

- = volume water returned each June, WMT, per unit area, if sprinklers used= 0.12 *324 ac-ft/1000 acres = 39 ac-ft/1000 acres.
- = volume water returned each June, WMT, per unit area, if gravity method used = 0.12 * 1109 ac-ft/1000 acres = 133 ac-ft/1000 acres.

The depletion volume per unit area (Second to last column each table part of Figure 4.5) is then the diversion (a negative value) plus the return flow (a positive value) volumes per unit area:

- = volume depletion each June, WMT, per unit area, if sprinklers used= -272 + 39= -233 ac-ft/1000 acres.
- = volume depletion each June, WMT, per unit area, if gravity method used = -414 + 133 = -281 ac-ft/1000 acres.

To convert the depletion in volume of water for the month to a daily flow rate per unit acreage, the above monthly totals are divided by the number of days in the month and by the conversion ratio:

(1 ac-ft per 43560 cubic feet) * (3600 seconds per hour) * (24 hours per day) = 1.9835 ac-ft per cfs-day

- = daily depletion rate each June, WMT, per unit area, if sprinklers used= -233 ac-ft/1000 acres / 30 days in June / 1.9835 ac-ft per cfs-day = -3.9 cfs per day per 1000 acres.
- = daily depletion rate each June, WMT, per unit area, if gravity method used = -281 ac-ft/1000 acres / 30 days in June / 1.9835 ac-ft per cfs-day = -4.7 cfs per day per 1000 acres.

These are the 2008 daily depletion values per 1000 acres for each irrigation method shown in the last columns of data in Figure 4.5. The next step is to express the depletions in terms of incremental changes since 1928.

**Step 8.**

The irrigated area, per 1000 acres, based on irrigation method, is summarized for the Willamette in Appendix D.7.6 of the Modified Flow report and Figure 4.6 below shows an image of that data. The 2010 Modified Flow report shows the following irrigated acreage for the Willamette Basin:

**D.7.6 Willamette Basin**

**Willamette (WMT)**

| | Irrigated acres (1000s of acres) | | |
|---|---|---|---|
| **Year** | **Sprinkler** | **Gravity** | **Total** |
| **1928** | 0.0 | 3.9 | 3.9 |
| **1950** | 48.8 | 5.8 | 54.6 |
| **1966** | 137.1 | 5.4 | 142.5 |
| **1978** | 214.4 | 5.1 | 219.5 |
| **1988** | 208.5 | 1.1 | 209.6 |
| **1999** | 186.6 | 3.2 | 189.8 |
| **2008** | 171.2 | 0.5 | 171.7 |

***Fern Ridge (FRN)**

| | Irrigated acres (1000s of acres) | | |
|---|---|---|---|
| **Year** | **Sprinkler** | **Gravity** | **Total** |
| **1925** | 0.0 | 0.0 | 0.0 |
| **1928** | 0.0 | 0.0 | 0.0 |
| **1950** | 1.0 | 0.0 | 1.0 |
| **1966** | 1.5 | 0.0 | 1.5 |
| **1978** | 1.5 | 0.0 | 1.5 |
| **1988** | 1.4 | 0.0 | 1.4 |
| **1999** | 1.4 | 0.0 | 1.4 |
| **2008** | 3.7 | 0.0 | 3.7 |

*** FRN irrigated acreage is included in WMT**

***Figure 4.6 Image of Appendix D.7.6, the surface water irrigated acreage per 1000 acres for some years for the irrigation methods for the two Willamette Basin subareas, from the 2010 Modified Flow report.***

Note that in the upper part of the figure, for WMT, the area irrigated by sprinklers increased from 1928 to 1978 and then decreased through 2008. The area irrigated by the gravity method increased between 1928 and 1950, then decreased through 1988, with one more increase in 1999 and a decrease in 2008. Overall, the total irrigated acres in WMT increased through 1978 and then decreased through 2008. In the lower part of the figure, for FRN, 2008 represents the largest irrigated acres, with all irrigation by sprinklers.

The irrigated area, in 1000s of acres, shown in the table above needs to be converted to the *incremental* irrigated acreage. Since the modified flows account for the current level of irrigation (based on 2008), the incremental irrigation is the difference between the 2008 value of irrigated acreage and the values shown for each year in Figure 4.6.

The incremental irrigated acreage, per 1000 acres, based on irrigation method, is summarized for the Willamette in Appendix D.8.6 of the Modified Flow report and Figure 4.7 below shows an image of that data.

**D.8.6 Willamette Basin**

**Willamette (WMT)**

| | Incremental Irrigated acres (1000s of acres) 2008 minus other years | | |
|---|---|---|---|
| **Year** | **Sprinkler** | **Gravity** | **Total** |
| **1928** | 171.2 | -3.4 | 167.8 |
| **1950** | 122.4 | -5.3 | 117.1 |
| **1966** | 34.1 | -4.9 | 29.2 |
| **1978** | -43.2 | -4.6 | -47.8 |
| **1988** | -37.3 | -0.6 | -37.9 |
| **1999** | -15.4 | -2.7 | -18.1 |
| **2008** | 0.0 | 0.0 | 0.0 |

**Fern Ridge (FRN)**

| | Incremental Irrigated acres (1000s of acres) 2008 minus other years | | |
|---|---|---|---|
| **Year** | **Sprinkler** | **Gravity** | **Total** |
| **1925** | 3.7 | 0.0 | 3.7 |
| **1928** | 3.7 | 0.0 | 3.7 |
| **1950** | 2.7 | 0.0 | 2.7 |
| **1966** | 2.2 | 0.0 | 2.2 |
| **1978** | 2.2 | 0.0 | 2.2 |
| **1988** | 2.3 | 0.0 | 2.3 |
| **1999** | 2.3 | 0.0 | 2.3 |
| **2008** | 0.0 | 0.0 | 0.0 |

***Figure 4.7 Image of the surface water irrigated acreage per 1000 acres for some years for the irrigation methods for the two Willamette Basin subareas from the 2010 Modified Flow report.***

The total irrigated acres (in 1000s of acres) for years 1925 through 1999 in Figure 4.6 are subtracted from the 2008 value for the irrigated acres for WMT from Figure 4.6 (171.2 acres), or 171.2 acres minus 186.6 acres for 1999 (WMT), which is -15.4 acres (in 1000s of acres) of incremental irrigated acres. Since this value is negative, it means that the correction will represent less irrigation than there used to be.

The next step will express the incremental areas as incremental depletions on a daily basis.

**Step 9.**

The incremental irrigated acreage, per 1000 acres, needs to be converted to the incremental depletions in daily flow rates. The incremental depletion in cfs is the depletion per unit area, in cfs/1000 acres, from the last columns of data in Figure 4.5, times the incremental irrigated acres, in 1000 acres, from the last column of Figure 4.7.

Using the June value of the sprinkler method depletion rate for WMT, from Figure 4.5, which was –3.9 cfs per 1000 acres, times the incremental irrigated acres per unit from Figure 4.7, which was -15.4 acres per 1000 acres, the incremental sprinkler method depletion rate for WMT for 1999 is +60.1 cfs.

Using the June value of the gravity method depletion rate for WMT, from Figure 4.5, which was -4.7 cfs per 1000 acres, times the incremental irrigated acres per unit from Figure 4.7, which was -2.7 acres per 1000 acres, the incremental gravity method depletion rate for WMT for 1999 is +12.7 cfs.

The total incremental depletion rate is the sum of the sprinkler and gravity method depletion rates, which is 60.1 + 12.7 = 72.8 cfs. Since the incremental irrigated acres is negative for 1999, that means that there is less irrigation now (in 2008) than there was in 1999.

The image below in Figure 4.8 from the 2010 Modified report describes how the different depletion data are for varying time periods, like yearly, monthly, or daily. (Incremental areas were yearly, Figure 4.7; water volume requirements were monthly, Figure 4.3; depletions rates for each month were calculated for daily cfs per 100 acres, Figure 4.5.)

> Note that the depletion per unit area values are monthly while the incremental area values are yearly. By multiplying these two values, monthly depletions are calculated for every year of the study. Daily depletion values are created from the monthly values by assigning a monthly value as a constant for every day of that month. With the formation of the daily depletion data, there are now a set of *D* values for each subarea.
>
> In the above calculations, depletion per unit area is multiplied by incremental acreage. It is assumed that the incremental part of the depletion calculation is from the incremental acreage. There is not an incremental component to the depletions per unit area portion of the equation. It is assumed that the depletion per unit area is constant through the years, whereas in actuality, the depletion per unit area values for sprinkler and gravity may be different in the past compared to now due to different types and proportions of crops, and different climatic conditions.

***Figure 4.8 Image from the 2010 Modified Flow report, page C-27.***

**Step 10.**

The incremental depletions, in cfs, were calculated for all the years shown in Figure 4.7 (from D.8.6) for both the WMT and FRN subareas.

The table below shows the incremental depletion calculations for the WMT subarea for 1999 as an example. The calculated incremental depletions for each month of 1999 are shown in the second to last data column, to one decimal place. The rounded values, shown in the last data column, are from the WMT5D record in the 2010 Modified Flow time series for each day of each month in 1999. Figure 4.9 shows the DSS plot for WMT5D for 1999, with the values plotted identical to the last data column in Table 4.1.

***Table 4.1 Willamette (WMT) Subarea Incremental Depletions, in cfs, for 1999.***

| **For 1999** | Depletion, cfs/1000 acres (from Figure 4.5) | | Incremental Irrigated acres (1000 acres) from Figure 4.7 | | Incremental Depletion, cfs (calculated) | | Total Incremental Depletion, cfs | |
|---|---|---|---|---|---|---|---|---|
| | Irrigation Method: | | Irrigation Method: | | Irrigation Method: | | Calculated | Rounded |
| Month | Sprinkler | Gravity | Sprinkler | Gravity | Sprinkler | Gravity | Value | Values |
| **Jan** | 0.2 | 0.7 | -15.4 | -2.7 | -3.1 | -1.9 | -5.0 | **-5** |
| **Feb** | 0.2 | 0.8 | -15.4 | -2.7 | -3.1 | -2.2 | -5.2 | **-6** |
| **Mar** | 0.2 | 0.7 | -15.4 | -2.7 | -3.1 | -1.9 | -5.0 | **-5** |
| **Apr** | 0.1 | 0.6 | -15.4 | -2.7 | -1.5 | -1.6 | -3.2 | **-4** |
| **May** | -1.4 | -1.7 | -15.4 | -2.7 | 21.6 | 4.6 | 26.2 | **27** |
| **Jun** | -3.9 | -4.7 | -15.4 | -2.7 | 60.1 | 12.7 | 72.8 | **73** |
| **Jul** | -7.6 | -9.9 | -15.4 | -2.7 | 117.0 | 26.7 | 143.8 | **144** |
| **Aug** | -7.0 | -8.9 | -15.4 | -2.7 | 107.8 | 24.0 | 131.8 | **132** |
| **Sep** | -3.0 | -3.1 | -15.4 | -2.7 | 46.2 | 8.4 | 54.6 | **54** |
| **Oct** | 0.4 | 1.5 | -15.4 | -2.7 | -6.2 | -4.1 | -10.2 | **-10** |
| **Nov** | 0.3 | 1.1 | -15.4 | -2.7 | -4.6 | -3.0 | -7.6 | **-8** |
| **Dec** | 0.2 | 0.7 | -15.4 | -2.7 | -3.1 | -1.9 | -5.0 | **-5** |

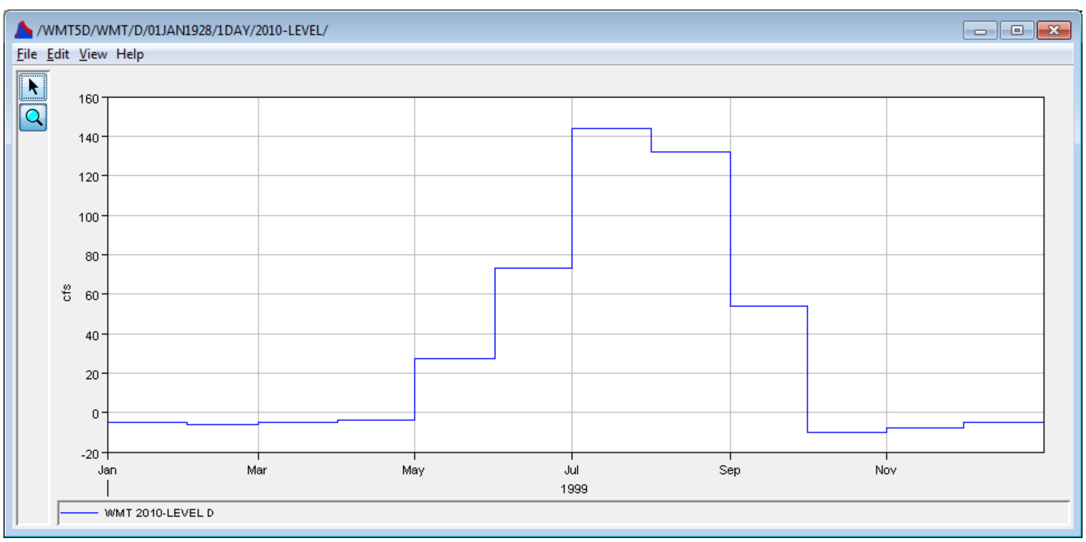


***Figure 4.9 Plot of WMT5D time series record for 1999, showing incremental depletion correction used in the 2010 Modified Flow dataset for WMT.***

The incremental depletions were calculated for a total of eight years in Figure 4.8, which were 1925, 1928, 19501, 1966, 1978, 1988, 1999, and 2008. The corrections for the years in-between those listed in Figure 4.8 were shaped to give a smooth transition, as shown below in Figure 4.10, which is the full time series plot of the record WMT5D. Note that the year with the maximum irrigated acres was 1978, and that year has the highest peak in Figure 4.10. The full time series graph shows a transition from mostly positive corrections to negative corrections just after 1970.

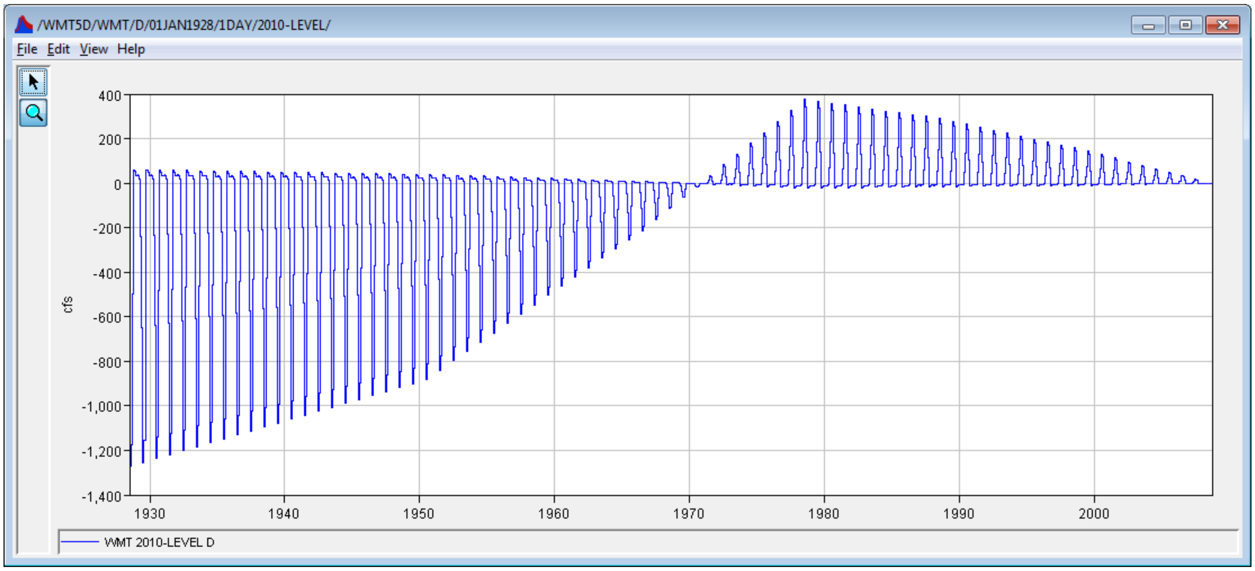


***Figure 4.10 Plot of WMT5D time series record for the POR, showing incremental depletion used in the 2010 Modified Flow dataset for WMT.***

The incremental depletions for Fern Ridge, the FRN area, are shown in Figure 4.11 for the full time series record FRN5D from the 2010 Modified Flow dataset.

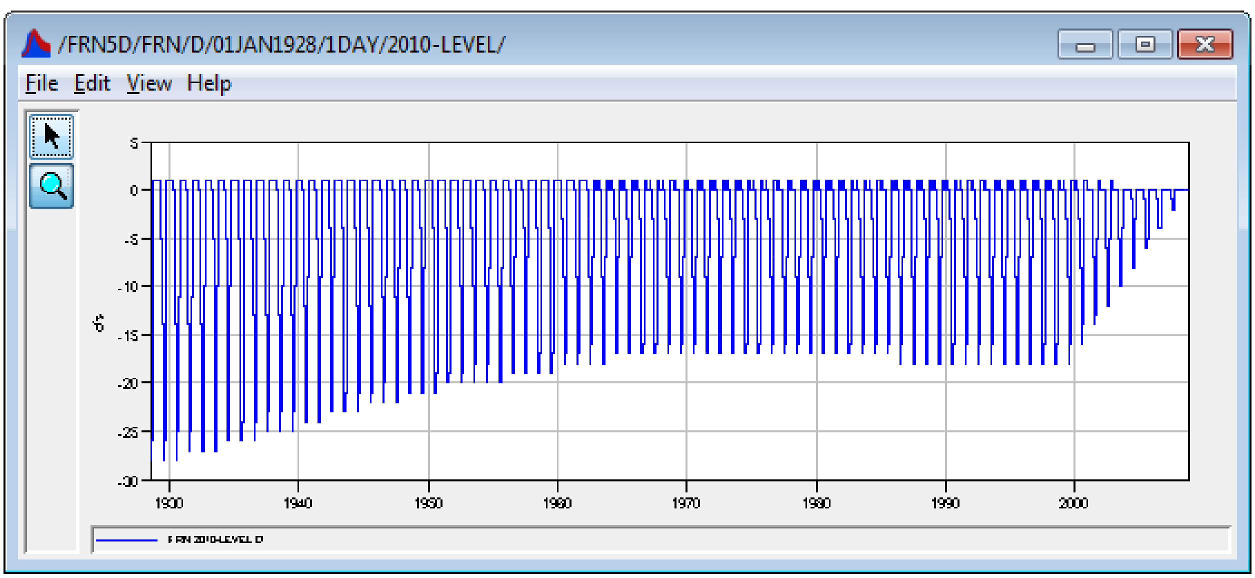


***Figure 4.11 Plot of FRN5D time series record for the POR, showing incremental depletion used in the 2010 Modified Flow dataset for FRN.***

There is also an adjustment for both subareas (WMT and FRN) to account for evaporation. These are time series records FRN5E and SVN5EE (for the T. W. Sullivan project at Willamette Falls) in the 2010 Modified Flow dataset.

The incremental depletion FRN5D and the evaporation correction FRN5E are applied directly to the daily time series of data for Fern Ridge to produce the inflow record to Fern Ridge reservoir, FRN5M. This record contains all the adjustments needed to represent the 2008 level of irrigation diversions and return flows for the area above Fern Ridge dam.

The adjustments for incremental depletion and evaporation for the Willamette subarea, WMT, were not all applied at a single location, as the FRN data was. The incremental depletions were applied as a percentage of WMT5D TO get the accumulated percentages of depletions at Albany (location code ALB), Salem (location code SLM), and Oregon City above the Falls (location code SVN, for T. W. Sullivan). Note that Figure 2.4 (from D.1.6) showed that 25% of WMT was upstream of Albany, 15% of WMT was between Albany and Salem (for an accumulated percentage of 25% + 15% = 40% at Salem), and 53% of WMT was between Salem and Willamette Falls (Sullivan, SVN). (Note the accumulated percentage of depletions at SVN is 25% + 15% + 53% = 93%.) There is a remaining 7% of WMT that applies downstream of Willamette Falls. The accumulated depletions are therefore:

$$ALB5DD = (0.25)*WMT5D$$
$$SLM5DD = (0.40)*WMT5D$$
$$SVN5DD = (0.93)*WMT5D$$

The equations used to make all flow adjustments in the Willamette Basin are shown in detail in the 2010 Modified Flow report in its Section 3.7.4.

# 5 Equivalent Water Volumes and Flows for Irrigation Demands in the 2010 Modified Flow Dataset for the Willamette Basin

This section outlines the water volume of irrigation demand within the Willamette Basin represented within the flow dataset. This water volume is also converted to an equivalent flow for 2008 level irrigation demand within the basin. Note that the demand in this section is not the same as the depletions calculated in the previous section, since depletion calculations also account for return flows. The irrigation demands in this section can be used to determine increases from the 2008 level to future demand to apply to the ResSim model, and the irrigation contracts in the basin that are in place for stored water can be compared to the total quantity of irrigation demand.

The data from Figure 4.5 (from Appendix D.6.6 in the 2010 Modified Flow report) provides the 2008 level flow rate per 1000 acres by month for WMT and FRN, for both irrigation methods, and Figure 4.6 provides the acreage (in 1000s acres) for the year 2008. Table 5.1 below shows these values converted to total water volume of demand. Table 5.2 shows the FRN values converted to water volume demand.

***Table 5.1 Willamette (WMT) diversion volumes and flows rates for 2008, 2010 Modified Flow report.***

| **For 1999** | Diversions in 2008, ac-ft/1000 acres (from Figure 4.5) | | Irrigated acres (1000 acres) for 2008 from Figure 4.7 | | Total Monthly Volume Of Diversions, ac-ft | | | Equivalent Daily Average Flow Rate For Diversions |
|---|---|---|---|---|---|---|---|---|
| | Irrigation Method: | | Irrigation Method: | | Irrigation Method: | | | Both Methods |
| Month | Sprinkler | Gravity | Sprinkler | Gravity | Sprinkler | Gravity | Both | cfs |
| **Apr** | -5.0 | -8.0 | 171.2 | 0.5 | 856.0 | 4.0 | 860.0 | 14.5 |
| **May** | -105.0 | -160.0 | 171.2 | 0.5 | 17976.0 | 80.0 | 18056.0 | 293.7 |
| **Jun** | -272.0 | -414.0 | 171.2 | 0.5 | 46566.4 | 207.0 | 46773.4 | 786.1 |
| **Jul** | -524.0 | -797.0 | 171.2 | 0.5 | 89708.8 | 398.5 | 90107.3 | 1465.5 |
| **Aug** | -490.0 | -745.0 | 171.2 | 0.5 | 83888.0 | 372.5 | 84260.5 | 1370.4 |
| **Sep** | -218.0 | -332.0 | 171.2 | 0.5 | 37321.6 | 166.0 | 37487.6 | 630.0 |
| **Oct** | -5.0 | -8.0 | 171.2 | 0.5 | 856.0 | 4.0 | 860.0 | 14.0 |

The data in Table 5.1 represents the total irrigation diversions for 2008 for the whole area defined as WMT. The WMT area has depletions proportioned for different stretches of the river according the schematic shown in Figure 2.4. These are described below:

The Albany (ALB) area, which has 25% of the depletions in WMT, includes all reaches and tributaries upstream of Albany to the dams: for the Long Tom River up to Fern Ridge Dam, for the McKenzie River up to Cougar and also Blue River, for the Coast Fork Willamette up to both Cottage Grove and Dorena Dams, up the Middle Fork Willamette to Dexter Dam and Fall Creek Dam, and the entire mainstem Willamette to Albany.

The Salem (SLM) area, which has 15% of the depletions in WMT, includes the mainstem and tributaries between Albany and Salem. The Santiam River confluence with the Willamette River is in this reach, so the 15% of WMT also includes diversions along the North Santiam River up to Big Cliff Dam and up the South Santiam River up to Foster Dam. This portion would include the diversions for Salem M&I.

The Sullivan (SVN) area, meaning the area between Salem and Oregon City above Willamette Falls, contains 53% of the depletions in WMT.

The remaining 7% of WMT depletions is for areas downstream of Willamette Falls and is not included in the ResSim model reaches.

Since the depletions are diverted water plus the return flows, and the return flows are a fixed monthly percentages of the diversions, the diverted water for irrigation in these subareas (ALB, SLM, and SVN) will be the same percentages as the depletions (25%, 15%, and 53%, respectively).

Table 5.2 below takes the proportions described in Figure 2.4 and applies those percentages to the 2008 demand values. The total volume for the full area and each subarea is shown in the last row of the table.

***Table 5.2 Willamette (WMT) diversion volumes and flows rates for 2008 for the defined percentages of the WMT area, 2010 Modified Flow report.***

| **For 1999** | Full WMT area Monthly Volume and Daily Flow Rate | | ALB, 25% WMT area Monthly Volume and Daily Flow Rate | | SLM, 15% WMT area Monthly Volume and Daily Flow Rate | | SVN, 53% WMT area Monthly Volume and Daily Flow Rate | |
|---|---|---|---|---|---|---|---|---|
| | Volume | Flow | Volume | Flow | Volume | Flow | Volume | Flow |
| Month | Ac-ft | cfs | Ac-ft | cfs | Ac-ft | cfs | Ac-ft | cfs |
| **Apr** | 860 | 14.5 | 215 | 3.6 | 129 | 2.2 | 456 | 7.7 |
| **May** | 18056 | 293.7 | 4514 | 73.4 | 2708 | 44.0 | 9570 | 155.6 |
| **Jun** | 46773 | 786.1 | 11693 | 196.5 | 7016 | 117.9 | 24790 | 416.6 |
| **Jul** | 90107 | 1465.5 | 22527 | 366.4 | 13516 | 219.8 | 47757 | 776.7 |
| **Aug** | 84261 | 1370.4 | 21065 | 342.6 | 12639 | 205.6 | 44658 | 726.3 |
| **Sep** | 37488 | 630.0 | 9372 | 157.5 | 5623 | 94.5 | 19868 | 333.9 |
| **Oct** | 860 | 14.0 | 215 | 3.5 | 129 | 2.1 | 456 | 7.4 |
| **Total:** | 278405 | | 69601 | | 41760 | | 147555 | |

The data in Table 5.2 indicates the volume of irrigation demand in the Willamette Basin in the 2010 Modified flow dataset. This total volume, and each subarea total volume, does not indicate the source of the water used for irrigation – the water volumes have not been broken out by stored water contracts or instream flow contracts (contracts for live flow).

Appendix D of the Willamette Project Supplemental Biological Assessment, Water Marketing Program, lists the water contracts from stored water in the Willamette projects and the river reaches from which the stored water may be withdrawn. The data from Appendix D is summarized below in Table 5.3. The reaches listed in Table 5.3 are defined in Figure 5.1. This data is from the Bureau of Reclamation (BOR) which executes the stored water contracts at the Willamette projects.

The stored water contracts that were in place in 2007 plus the new contract requests in 2007 are summed in Table 5.3, with this total shown in the right-hand column. The total is a little over 80 Kaf of stored water contracts. The stored water contracts (existing and requested) is about 30% of the total irrigation in the Willamette in the 2010 Modified flow dataset, since the total water volume depletion for irrigation shown in Table 5.2 is 278 Kaf.

***Table 5.3 Summary of Willamette Basin Water Service Contracts. (From Appendix D, Water Marketing Program.) Contracts are for irrigation, not M&I.***

| **Reach Number (See Fig. 5.1 for definition)** | Existing Contracts in 2007, Total Acre-Feet of Stored Water Contracts | Requests for New Contracts for Stored Water in 2007, in Acre-Feet | Combined Volume of Stored Water Contracts, in Acre-Feet |
|---|---|---|---|
| **1** | 6760.050 | 16515.270 | 23275.32 |
| **2** | 1485.050 | 350.000 | 1835.05 |
| **3** | 9473.545 | 2795.500 | 12269.045 |
| **4** | 1096.110 | 78.500 | 1174.61 |
| **5** | 3631.390 | 8793.150 | 12424.54 |
| **6** | 24052.875 | 541.400 | 24594.275 |
| **7** | 570.000 | 198.750 | 768.75 |
| **8** | 1640.115 | 100.050 | 1740.165 |
| **9** | 9.500 | - | 9.5 |
| **10** | 135.730 | 823.000 | 958.73 |
| **11** | 92.000 | 2.750 | 94.75 |
| **12** | 12.500 | - | 12.5 |
| **13** | 1164.550 | 1.500 | 1166.05 |
| **14** | 51.000 | - | 51 |
| **15** | 56.387 | - | 56.387 |
| **Total:** | 50230.802 | 30199.870 | 80430.672 |

There are several things to note about the demand volumes in Tables 5.2 and 5.3 and some summary points about the flow dataset:

- The calculated amounts are diversions only, not return flows. Any differential irrigation diversions modeled in the WBR alternatives will also have return flows calculated using the monthly percentages shown in Figure 4.5 (Appendix D.6.6), which are distributed throughout the whole year.
- No municipal and industrial (M&I) withdrawals (or their return flows) were corrected for in the 2010 Modified Flows. The M&I historical use was intrinsically embedded in the observed flow data used for every year of the 2010 Modified Flows, but no corrections were made to make all those years in the POR have the same level of M&I. The WBR demand analysis will include M&I, and the difference in future M&I needs from current M&I demands will be applied as withdrawals from reaches in the ResSim model for future alternatives. The differential M&I demand will also have a return flow estimate calculated for inclusion in the model.
- The diversion information used to develop the 2010 Modified Flows is not based on contract amounts, but on irrigated areas, crops, and water needed for each crop.
- The demands for the WBR alternatives will be grouped into the same 15 reaches as defined in Table 5.3 and Figure 5.1, with the 2008 demand level subtracted from future demand estimates by reach for each alternative. (It is the increase in demand that is modeled, since current demand is embedded within the flow dataset.) Within any of the subareas ALB, SLM, and SVN, the demand differences may be applied along any reach, but since local flows are only available in a few places in the Willamette, only the accumulated effects at Albany, Salem, and Oregon City above Willamette Falls will be determined.

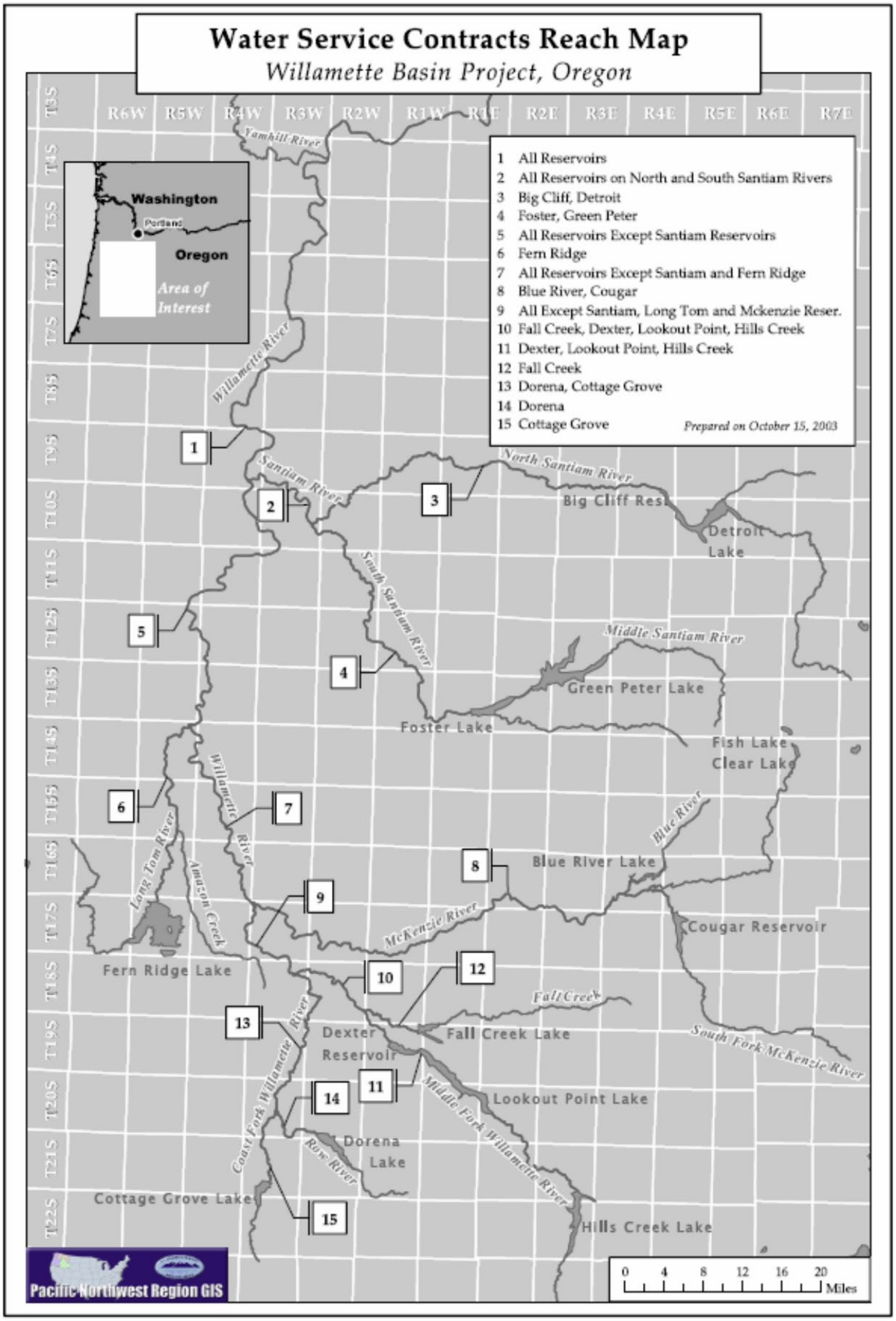


***Figure 5.1 Reach numbering designation used in the Willamette River Basin. Map pulled from Appendix D, Water Marketing Program, from the Supplemental Biological Assessment.***

# 6 References.

Appendix D, Water Marketing Program, Willamette Project Supplemental Biological Assessment, U.S. Army Corps of Engineers, Bonneville Power Administration, Bureau of Reclamation, May 2007.

Bonneville Power Administration. (2011). 2010 Level Modified Streamflows. Portland: Bonneville Power Administration.