# Introduction

Add history of models for Jim.

The Corps’ thirteen multipurpose dams and reservoirs in the Willamette River Basin are operated as a system, not as independent entities. All projects in the basin share the various functions included in an overall water resources management plan designed to provide flood damage reduction, hydropower generation, irrigation, navigation, recreation, and water quality throughout the basin. Changes in the way a project is operated can have an effect on the system, and so the change must be analyzed before implementation. Numerous changes can have a significant effect on the operation of the system and must be analyzed carefully to evaluate the response of the system to the change in operation.

The Willamette River Basin was modeled using the program HEC-Res-Sim, which is the Corps Hydrologic Engineering Center’s Reservoir System Simulation program, to assess the effects of various operational measures discussed in this report. This program is used to model reservoir systems whose operations are defined by a variety of goals and constraints. The HEC-ResSim model is designed to simulate reservoir operations at one or more reservoirs whose operations are defined by a variety of operational goals and constraints, including downstream flow limitations. The model uses a rule-based description of the operational goals and constraints that reservoir operators must consider when making release decisions. The dam is the root of an outlet hierarchy or “tree” which allows the user to describe the different outlets of the reservoir in as much detail as is deemed necessary. The ResSim model is not an optimization tool and can only be used to simulate rule-based reservoir operations input by the modeler. The model does not run in a forecast mode, it makes decisions based on current system status and current inflows. Additional information on the ResSim model can be found on the USACE Hydrologic Engineering Center website.

In Res-Sim, all projects are configured with their physical constraints and capabilities. Geographic information, such as river mile location and elevation above sea level, are also specified. Each reservoir also has an operation set associated with it. The operation set is first broken into zones, based on pool storage or elevation levels as a function of day of year, and then a set of instructions within that zone that describes how the reservoir is operated. These instructions are called rules, and are prioritized within each zone. The program calculates each reservoir’s flow release at each time step to meet the highest priority rule possible based on the physical capability for that project. The program progresses through each time step calculation until the simulation is complete.

The Willamette Basin ResSim tool has been updated in 2010 to simulate Biological Opinion (NMFS 2008) operations as well as winter flood control operations as prescribed in the project Water Control Manuals (WCMs). This document briefly summarizes the model and the operations within the model.

# Basin Description

The Willamette River, a major tributary of the Columbia River, is 187 miles long and is located in northwestern Oregon (Figure 1). The main stem of the Willamette River is formed by the confluence of the Middle and Coast Forks of the Willamette River near Springfield, Oregon. The main stem flows north for 187 miles to the Columbia River. Significant tributaries of the Willamette River, from source to mouth, include the Middle and Coast Fork Willamette, the McKenzie, Long Tom, Marys, Calapooia, Santiam, Luckiamute, Yamhill, Molalla, Tualatin, and Clackamas rivers.

The Willamette River basin contains thirteen dams (see Figure 2). The upstream-most dams are located on the three tributaries that form the Willamette River, which include the Coast Fork, Middle Fork, and McKenzie River. The main stem of the Willamette River is formed from the Middle Fork, which includes four dams. The upstream-most project on this reach is Hills Creek Dam. The Middle Fork flows for 26.5 river-miles in a northwest direction until it becomes impounded by Lookout Point Dam. Approximately three miles downstream is Dexter Dam, which regulates the power-generating water releases from Lookout Point. The fourth dam along the Middle Fork impounds Fall Creek Lake, located east of Dexter Dam. From its confluence with Fall Creek, the Middle Fork of the Willamette River flows in a northwest direction for about 12 miles until it meets the Coast Fork of the Willamette River. There are two dams along the Coast Fork of the Willamette River, including Cottage Grove Dam and Dorena Dam. Cottage Grove Dam is located about 30 river miles upstream from the confluence of the Middle and Coast Fork tributaries. Six miles east of the town of Cottage Grove is Dorena Lake, which impounds Row River.

The McKenzie River joins the Willamette River approximately seven river-miles downstream of Eugene, OR. Cougar Dam is the most upstream project on this reach, and impounds the South Fork of the McKenzie River about 4.5 river-miles above the main stem of the McKenzie River. Flowing west for about three miles, the Blue River joins the McKenzie. Flow from the Blue River is regulated by the Blue River Dam, which is located approximately 1.7 river-miles upstream from its confluence with the McKenzie River. After combining with the McKenzie River, the Willamette River flows north through the city of Harrisburg. The next dam, Fern Ridge, is located on the Long Tom River 25.7 river-miles upstream from its confluence with the Willamette River. The Willamette River flows through the city of Corvallis and continues through Albany. Between the city of Albany and Independence, the Santiam River joins the Willamette River. There are four dams located in the Santiam River basin: two on the North Santiam River, and two on the South Santiam River. Green Peter Dam impounds the Middle Santiam River, which is a tributary of the South Santiam River.

Six river-miles downstream is Foster Dam, which regulates the power-generating flow from Green Peter Dam. Detroit Dam impounds the North Santiam River, and Big Cliff Dam regulates its releases.

All thirteen multi-purpose dams were constructed by the U.S. Army Corps of Engineers (USACE). *The primary purpose of these projects is to prevent flood damages to the downstream metropolitan areas of the Willamette Valley* but other purposes include: hydropower generation, recreational use and water supply. The regulation of flood storage in each reservoir is coordinated with the regulation of flood storage in all of the other reservoirs. Table 1 presents a summary of the reservoir and outlet works features for the Willamette Basin projects. A general description of each project follows.

The Willamette River Basin covers 11 counties in Oregon comprising two-thirds of Oregon’s population including the state’s largest city, Portland, and capitol city, Salem. Communities along the main stem at risk of flooding include Springfield and Eugene in Lane County; Harrisburg in Linn County; Corvallis in Benton County; Albany in Linn and Benton Counties; Salem in Marion County; Newberg in Yamhill County; Oregon City, West Linn, Milwaukie, and Lake Oswego in Clackamas County, and Portland in Multnomah and Washington counties.

The Willamette River is known for flooding because of the high amounts and variations of precipitation in the valley. The largest flood on the Willamette River, in recorded history, occurred in 1861 when rainstorms and warm temperatures combined with a well-above-average snowpack in the Cascades. From Eugene to Portland, thousands of acres of riverside farmland were washed away and many towns in the valley were damaged or destroyed. Peaking at 635,000 cubic feet per second, the 1861 flood inundated approximately 353,000 acres of land.

Although the Willamette River is regulated and controlled by a complex system of dams, severe flooding is still a concern. In 1996, a high snowpack combined with massive rainfall and warm temperatures, caused some of the costliest floods to ever affect the Willamette Valley.

The United States Geological Survey (USGS) operates four stream gages along the main stem Willamette River, at Harrisburg, Albany, Salem, and Portland (Figure 2).

# Project Descriptions

## Hills Creek Reservoir (HCR)

Hills Creek Dam is the upstream-most project of the thirteen dams, and one of four dams along the Middle Fork of the Willamette River. Construction of the dam was initiated in 1956 and completed in 1962.

The drainage area above the dam is approximately 389 square miles. The 2,235-foot dam embankment (earth and gravel fill, 20-ft wide and about 304-ft tall) is located on the Middle Fork about 47.8 miles above the confluence with the Willamette River. Reservoir features and their associated storage volumes are shown in Table 1. The outlet works are located in the right abutment and consist of an intake tower, tunnel, and stilling basin. Control of the discharge is provided by 2 hydraulically operated slide gates (6.5-ft wide by 12.5-ft high) located in a single gate chamber. One gate serves as the operating gate, while the other gate serves as an emergency gate.

## Lookout Point Reservoir (LOP)

Lookout Point Dam is located in Lane County, about 22 miles southeast of the city Eugene, OR. The 1,874.8-ft dam embankment (a rolled earth-fill dam, 24-ft wide at its crest) is located on the Middle Fork of the Willamette River 26.5 river miles downstream of the Hills Creek reservoir, and approximately 20 river miles above the confluence with the Coast Fork Willamette River. The drainage area above the dam is approximately 991 square miles. Dam construction began in 1947 and was completed in 1954.

The top of dam elevation is 941.0 feet above mean sea level (National Geodetic Vertical Datum of 1929), and Table 1 shows the features for the Lookout Point reservoir. The spillway located in the river section of the dam near the right abutment consists of five 42.5-ft bays and four 9-ft piers for a total length of 248.5-ft. It has a crested weir with an elevation of 887.5-ft. Discharge is controlled by five tainter gates. The outlet works are located near the left abutment and consists of four gated conduits that pass through the spillway into the stilling basin. Each of the conduits are regulated by 6.75-ft by 12-ft hydraulically operated Walker-type tainter valves.

## Dexter Reservoir (DEX)

Dexter Dam began construction in 1953 and was completed in 1955. Located on the Middle Fork of the Willamette River, Dexter Dam is three river miles downstream of Lookout Point Reservoir. The dam operates to re-regulate flows from Lookout Point in order to maintain a uniform flow downstream, as well as to provide additional hydropower generation.

Dexter Dam has an earth-fill section (24-ft wide and 2,319-ft long) and concrete section that is connected with the right abutment. The spillway is located near the right abutment, which consists of seven 44-ft bays and six 8.5-ft piers for a total length of 359-ft. The crested weir is at elevation of 201.2-ft, and directs flow into a rectangular shaped stilling basin. Flow entering the spillway is controlled by seven 44-ft wide by 35-ft high tainter gates. There are no outlet gates at Dexter Dam. All releases that are not used for hydroelectric power generation are made through the spillway gates.

## Fall Creek Reservoir (FAL)

Fall Creek Dam is located in Lane County, about 18 miles southeast of the city Eugene, OR. The 5,100-ft dam embankment (quarried granular and select rock) is located on Fall Creek, which is a tributary to the Middle Fork of the Willamette River. The dam is located about seven miles above the mouth of Fall Creek. The drainage area above the dam is approximately 184 square miles. Dam construction was authorized in 1950 and completed in 1966.

Table 1 shows the features for the Fall Creek reservoir. The ogee-type spillway is located in the left abutment, and is 90-ft long. Flow from the spillway is discharged into an unlined channel that leads directly into the river. There is no stilling basin below the spillway. The outlet works are located near the left abutment and consists of an intake structure, a domed underground gate structure, twin box-culverts extending through the dam, and a stilling basin as the downstream end.

## Cottage Grove Reservoir (COT)

Cottage Grove Dam is located on the Coast Fork of the Willamette River, five miles south from the city of Cottage Grove. The dam impounds the Coast Fork 29.7 miles above its confluence with the Willamette River. The drainage area above the dam is approximately 104 square miles. Dam construction began in 1939 and was completed in 1942.

The embankment dam consists of a rolled-earth section across the flood plain with a concrete spillway section near the right bank of the river, totaling 2,110-ft in length. The earth-fill section is 1,750-ft long and the remaining 360-ft is concrete. The ogee, free-overflow type spillway is located in the river channel between the embankment section and the concrete non-overflow section. The 264-ft long spillway directs flow over a paved apron for 137-ft below the dam, which is designed to produce a drowned hydraulic jump near the toe of the dam. There is no stilling basin below the spillway. The outlet works are located near the right side of the spillway section and discharge onto the spillway apron. Flow is discharged through three 62-ft long conduits that are controlled by hydraulic slide gates.

## Dorena Reservoir (DOR)

Dorena Dam is located on a tributary of the Coast Fork Willamette River, Row River. The dam impounds Row River 7.6 miles above its confluence with the Coast Fork River. The drainage area above the dam is approximately 265 square miles. Dam construction began in 1947 and was completed in 1950.

The embankment dam consists of a 2,600-ft long earth-fill section with a 700-ft concrete-gravity spillway section near the right abutment, totaling 3,300-ft in length. The spillway is a 200-ft long free-overflow structure that discharges into a stilling basin. The stilling basin design includes two rows of baffles and slopes, and a 16-ft step-up at the lower end. The outlet works are located in the concrete spillway section and discharge onto the spillway face. Flow is passed through five conduits, which are controlled by hydraulic slide gates.

## Fern Ridge Reservoir (FRN)

Fern Ridge Dam is located on the Long Tom River, which feeds directly into the Willamette River. The dam spans across Long Tom River and Coyote Creek, two miles above their natural confluence. The drainage area above the dam is approximately 252 square miles. Dam construction began in 1940 and was completed in 1941. Fern Ridge is the oldest dam in the Willamette Valley Project.

The earth-filled embankment consists of a 310-ft left abutment, a 294-ft concrete section, a 6,006-ft right abutment, and two low dike sections that total 5,060-ft in length. The total length of the dam is 11,670-ft. Both the spillway and outlet works are located in the concrete section of the dam. The spillway has an ogee-shaped crest with six separate bays, and empties into a 300-ft wide, flat downstream channel. Discharge through each of the bays is controlled by 34-ft by 17.7-ft tainter gates. There is no stilling basin. The outlet works consists of four gated regulating outlets, a sluice gate, and a diversion system into Coyote Creek. The regulating outlets each consist of a 6.75-ft by 9.33-ft lift gate which are designed to control larger releases. The single 3-ft by 3-ft sluice gate is designed to control smaller project release requirements which might be difficult for the regulating outlets.

## Cougar Reservoir (CGR)

Cougar Dam is located on the South Fork McKenzie River, a tributary of the main stem of the McKenzie River. The dam impounds the South Fork McKenzie River 4.4 miles above its confluence with the McKenzie River. The drainage area above the dam is approximately 208 square miles. Dam construction began in 1956 and was completed in 1963.

Cougar Dam is a 1,500-ft long embankment (rock-fill) with a spillway structure. The spillway section is an 89-ft long ogee-type structure that is located in the right abutment. Flow from the spillway discharges into a 90-ft long chute. There is no stilling basin included in the design. The outlet works are located in the left abutment and include an intake structure with a regulating tunnel, totaling 993-ft in length. There are two entrances to the intake structure. Flow is controlled by two hydraulic 6.5-ft by 12.5-ft slide gates at each entrance. One gate serves as the operating gate, while the other gate serves as an emergency gate.

## Blue River Reservoir (BLU)

Blue River Dam is located on the Blue River, which feeds into the main stem of the McKenzie River. The dam impounds the Blue River 1.8 miles above its confluence with the McKenzie River. The drainage area above the dam is approximately 88 square miles. Dam construction began in 1963 and was completed in 1968.

Blue River Dam is an earth and rock-fill embankment and totals 1,250-ft in length. The spillway section is a 70-ft long ogee-type structure that is located in the left abutment. The outlet works are also located in the left abutment and include an intake tower structure, regulating outlet tunnel, and a stilling basin. The two outlets are controlled by 4.75-ft by 8-ft gates at the upstream end. At the downstream end there are two slide gates for each outlet, one serves as an operating gate while the other serves as an emergency gate. In addition, one 14-in diameter and one 18-in diameter low-flow by-passes are included to allow low-flow releases without using the regulating slide gates. A secondary embankment dam is located on the left side of the reservoir approximately three miles upstream from the main site that is 1,535-ft long.

## Green Peter Reservoir (GPR)

Green Peter Dam is located 5.5 river miles above the mouth of the Middle Santiam River, which feeds the larger South Santiam River. The drainage area above the dam is approximately 277 square miles. Dam construction began in 1963 and was completed in 1967.

Green Peter Dam is a concrete gravity structure with a gated spillway. The dam is 1,380-ft long, 90-ft of which is the spillway section. The ogee-type spillway is located near the central section of the dam and discharge into the stilling basin below the dam. The outlet works consists of two conduits which are located below the spillway. Releases from each outlet are controlled by two slide gates, one serves as an operational gate and the other serves as an emergency gate.

## Foster Reservoir (FOS)

Foster Dam is located on the South Santiam River about seven river miles below the Green Peter Dam. The purpose of Foster Dam is to reregulate releases from the Green Peter Dam to maintain a uniform flow in the South Santiam River. The drainage area above the dam is approximately 494 square miles. Dam construction began in 1964 and was completed in 1967.

Foster Dam is a gravel and quarried rock fill structure with a concrete section. The dam is 4,800-ft long, 180-ft of which is the spillway structure. The concrete gravity-type spillway is located in the channel section of the dam and consists of four bays, each controlled by a 45-ft by 44.6-ft tainter gate. The 180-ft long spillway discharges into a stilling basin that is 210-ft long and 169-ft wide. There are no outlet works at Foster Dam. All releases not used for power generation are made through the spillway.

## Detroit Reservoir (DET)

Detroit Dam is located on the North Santiam River about 48.5 miles above its confluence with the main stem of the Santiam River. The two projects on the North Santiam River are the downstream-most dams in the Willamette Valley Project. The drainage area above the dam is approximately 438 square miles. Dam construction began in 1949 and was completed in 1953.

Detroit Dam is a straight concrete-gravity structure. The dam is 1,524-ft long, 294.5-ft of which is the spillway structure. The spillway is located near the center of the dam and consists of six bays, each controlled by a 42-ft by 32.6-ft radial gate. The crest of the spillway is at elevation 1,541, which is 371-ft above the floor of the stilling basin. The outlet works consists of two tiers of two conduits, which are located in the spillway section at elevation 1,265.33 and elevation 1,340.0. The releases from the outlets are controlled by 5.33-ft by 10-ft hydraulic fixed-wheel gates. All releases not used for power generation are made through the spillway. Flows made through the outlets and over the spillway are discharged into a stilling basin that is 250-ft long and 294.5-ft wide.

## Big Cliff Reservoir (BCL)

Big Cliff Dam is located on the North Santiam River about three river miles below the Detroit Dam. The purpose of Big Cliff Dam is to reregulate releases from Detroit Dam to maintain a uniform flow in the North Santiam River. The drainage area above the dam is approximately 452 square miles. Dam construction began in 1950 and was completed in 1953.

Big Cliff Dam is a straight concrete-gravity structure. The dam is 295-ft long, 156-ft of which is the spillway structure. The concrete gravity-type spillway is located in the channel section of the dam and consists of three bays, each controlled by a 46-ft by 45.5-ft radial gate. Flows from the spillway discharge into a paved stilling basin that is 190-ft long and 156-ft wide. There are no outlet works at Big Cliff Dam. All releases not used for power generation are made through the spillway.

Table 1. Willamette Basin Projects: Reservoir and Outlet Works

| Reservoir Feature | Willamette Valley Project Reservoirs | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HCR | LOP | DEX | FAL | COT | DOR | FRN | CGR | BLU | GPR | FOS | DET | BCL |
| Min. Power Pool (kaf) | 106.7 | 106.6 | - | - | - | - | - | 43.5 | - | 120.0 | - | 115.0 | - |
| Min. Conservation Pool (kaf) | 155.4 | 118.8 | - | 9.6 | 3.1 | 7.1 | 2.8 | 52.2 | 4.0 | 159.9 | 31.1 | 154.4 | - |
| Spillway Crest (kaf) | 242.2 | 293.5 | 3.3 | 60.5 | 32.9 | 77.6 | 12.3 | 151.2 | 58.0 | 275.8 | 17.9 | 363.2 | 1.17 |
| Max. Conservation Pool (kaf) | 350.0 | 443.0 | - | 117.8 | 31.8 | 72.1 | 97.3 | 189.0 | 82.8 | 409.8 | 55.9 | 436.0 | - |
| Full Pool (kaf) | 355.6 | 456.0 | 27.3 | 125.1 | 32.9 | 77.6 | 97.3 | 200.0 | 89.5 | 428.1 | 60.8 | 455.1 | 4.7 |
| Max Pool (kaf) | 355.6 | 477.7 | 29.7 | 125.1 | 47.5 | 131.1 | 111.4 | 200.0 | 89.5 | 428.1 | 60.8 | 472.6 | 5.3 |
| Top of Dam (kaf) | 370.6 | >504.5 | - | 134.8 | - | - |  | - | - | 446.9 | - | - | - |
| Available Storage to Full Pool (kaf) | 200.2 | 337.2 | - | 115.5 | 29.8 | 70.5 | 94.5 | 147.8 | 85.5 | 268.2 | 29.7 | 300.7 | - |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Is Spillway Used? | No | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes |
| Number of Spillbays | 3 | 5 | 7 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 4 | 6 | 3 |
| Capacity of 1 bay at Full Pool (cfs) | 42,500 | 41,862 | 35,400 | - | 40,800 | 0 | - | - | - | - | 41,100 | 24,290 | 59,670 |
| Total Capacity at Min Cons. Pool (cfs) | - | - | - | - | - | - | - | - | - | - | 40,000 | - | - |
| Total Capacity at Max Cons. Pool (cfs) | 130,000 | 194,000 | - | 70,000 | - | - | 45,000 | - | 37,500 | 92,500 | 170,000 | 98,580 | - |
| Total Capacity at Full Pool (cfs) | 141,500 | 222,000 | 242,000 | 82,500 | 40,800 | 0 | 45,000 | - | 53,200 | 110,000 | 200,000 | 145,740 | 179,000 |
| Total Capacity at Max Pool (cfs) | 141,500 | 270,000 | 267,000 | 82,500 |  | 97,500 | - | - | 53,200 | 110,000 | 200,000 | 191,640 | 179,000 |
| Crest Elevation (ft) | 1,495.50 | 887.50 | 660 | 834 | 791.00 | 835.00 | 358.50 | 1,656.75 | 1,321.00 | 968.70 | 596.80 | 1,541 | 1,161.50 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Number of Regulating Outlets | 2 | 4 | 0 | 2 | 3 | 5 | 4 | 2 | 2 | 2 | 0 | 4 | 0 |
| RO Capacity of 1 RO at Max Pool (cfs) | 6,200 | 6,100 | - | 3,900 | 1,287 | 1,850 | 2,075 | 7,500 | 4,200 | 6,600 | - | 7,480 | - |
| RO Capacity of 1 RO at Min Pool (cfs) | 3,000 | 4,000 | - | 2,400 | 810 | 1,080 | 1,120 | 3,600 | 1,855 | 4,740 | - | 5,780 | - |
| Total Capacity of all RO's at Max Pool (cfs)  8 | 10,760 | 24,400 | - | 7,800 | 3,860 | 9,275 | 8,260 | 12,050 | 8,400 | 13,210 | - | 28,010 | - |
| Total Capacity of all RO's at Min Pool (cfs) | 5,600 | 16,300 | - | 4,790 | 2,430 | 5,440 | 4,560 | 5,920 | 3,710 | 9,480 | - | 19,780 | - |
| Invert elevation (ft) | 1,409 | 724 | - | 670 | 719 | 739 | 340 | 1,478.75 | 1,132 | 745 | - | 2 at elev 1,340 | - |
|  |  |  |  |  |  |  |  |  |  |  |  | 2 at elev 1,265 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Number of Turbines | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 2 | 1 |
| Nameplate capacity at full pool (MW/unit) | 15 | 40 | 15 | - | - | - | - | 12.5 | - | 40 | 10 | 50 | 18 |
| Capacity per Turbine at Min Pool (cfs) | 850 | 2,700 | 4,200 | - | - | - | - | 690 | - | 2,210 | 1,710 | 2,480 | 3,200 |
| Capacity per Turbine at Max Pool (cfs) | 750 | 2,400 | 4,200 | - | - | - | - | 455 | - | 1,800 | 1,330 | 1,950 | 2,810 |
| Total Cap. at Full Load at Min Pool (cfs) | 1,700 | 8,100 | 4,200 | - | - | - | - | 1,380 | - | 4,420 | 3,420 | 4,960 | - |
| Total Cap. at Full Load at Max Pool (cfs) | 1,500 | 7,200 | 4,200 | - | - | - | - | 910 | - | 3,600 | 2,660 | 3,900 | - |
| Intake Invert elevation (ft) | 1,384 | 724 | 634.0 | - | - | - | - | 1,253 | - | 810 | 525 | 1,395.5 | 1,130 |

# Model Setup –

## Configuration

The model configuration for the Willamette ResSim model is shown in Figure 1. Key features of the basin model are described below in Section xx and specific project information is presented in more detail in Section x.

Two Reservoir Networks have been developed:

* Hourly Model - SSARR routings many places, with MC routing or null in others. Routings based on work by Matt Fraver.
* SSARR Daily Model - SSARR routing or null in all areas set up for daily time steps only.

The Willamette Basin model includes the following key features by sub-basin:

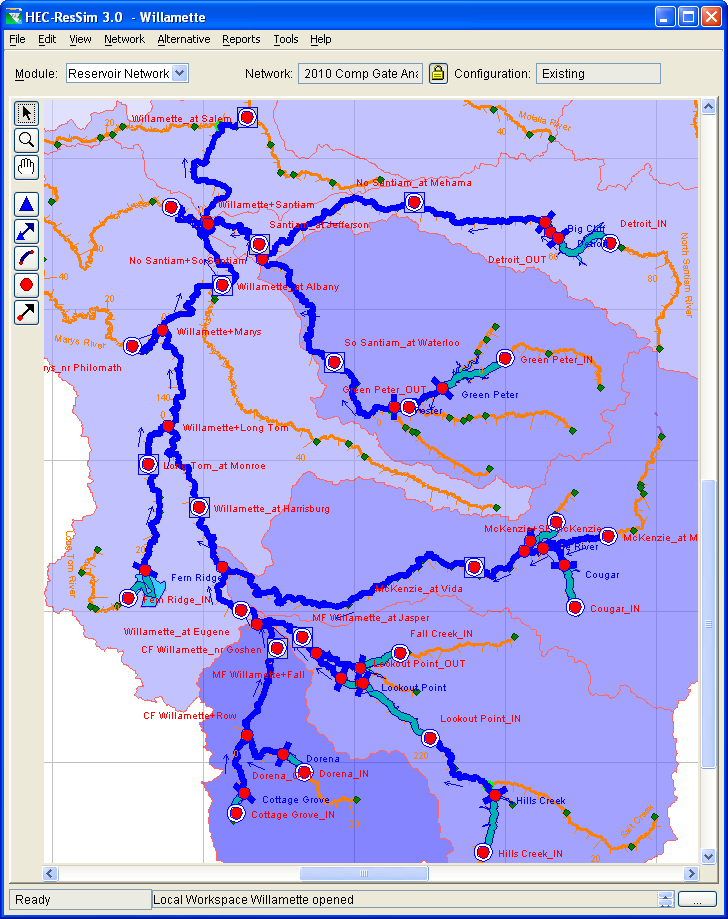
|  |  |  |
| --- | --- | --- |
| **Junctions** | **Inflows** | **Locals** |
| **Hills Creek Inflow** | **√** |  |
| **Lookout Point Inflow** |  | **√** |
| **Fall Creek Inflow** | **√** |  |
| **Jasper Gage** **Control Point** |  | **√** |
| **Cottage Grove Inflow** | **√** |  |
| **Dorena Inflow** | **√** |  |
| **Goshen Gage Control Point** |  | **√** |
| **Cougar Inflow** | **√** |  |
| **Blue River Inflow** | **√** |  |
| **Vida Gage Control Point** |  |  |
| **Fern Ridge Inflow** | **√** |  |
| **Monroe Gage Control Point** |  | **√** |
| **Green Peter Inflow** | **√** |  |
| **Foster Inflow** |  | **√** |
| **Waterloo Gage Control Point** |  | **√** |
| **Detroit Inflow** | **√** |  |
| **Mehama Gage Control Point** |  | **√** |
| **Jefferson Gage Control** |  | **√** |
| **Harrison Gage Control Point** |  | **√** |
| **Albany Gage Control Point** |  | **√** |
| **Salem Gage Control Point** |  | **√** |

**Table 2**. Modeled Reservoirs **Table 3**. Model Junctions and Flow Sources

|  |
| --- |
| **Reservoirs** |
| **Hills Creek** |
| **Lookout Point** |
| **Dexter** |
| **Fall Creek** |
| **Cottage Grove** |
| **Dorena** |
| **Cougar** |
| **Blue River** |
| **Fern Ridge** |
| **Green Peter** |
| **Foster** |
| **Detroit** |
| **Big Cliff** |

A snapshot of the Res-Sim model of the Willamette River Basin that used for the operational measures analyzed in this report is shown below in **Figure 1**. The orange lines represent part of the Watershed, which are the building blocks of the reservoir model outlining the streambeds and calculation points (green dots). The dark blue represents a system of river reaches superimposed on the streamlines. The river reaches are connected at junction points (shown as red dots), with the red dots outlined by squares representing the control points. Junctions outlined with a white circle have a local flow component added in. The thirteen Corps dams are input as reservoirs and shown as light blue, with the smallest reservoirs (Foster and Big Cliff) not visible at the scale of the figure.

**Figure 1. Willamette Basin ResSim Network Configuration**



### Routing in Hourly Model

The legacy HEC-5 model for the Willamette Basin included primarily SSARR routings, which was a routing method developed for the Pacific Northwest in the 1960’s. The SSARR routing is based on a timing equation, TS = KTS/Q^n, where the time of storage in the reach is TS, Q is the flow, and KTS and n are parameters determined through hydrologic analyses. Some routings were refined in 2010 by WEST Consultants using the 8-point channel Muskingum-Cunge routing. The routing method by reach and the SSARR routing parameters are shown in Table 4. SSARR storage interpolation tables are shown in Table 5. The routing shown in these two tables were used to compute the local flows.

The routings are defined in a way that each reservoir’s flow toward a control point goes through one reach with SSARR routing and all other reaches null routing, but the time to travel through the SSARR designated reach is the same as would physically occur through the entire stretch of SSARR plus null routing. This form of specification reduces the computation time of each simulation.

Table 4. Summary of Routing by Reach for Willamette Hourly Model

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Local Sub-basin | River | Reach Name | FINAL Routing | KTS | n | sub-reaches | |
| Lookout Point | Middle Fork Willamette | Hills Creek\_OUT to MF Willamette\_abv Salt Cr nr Oakridge | Null |  |  |  | |
| MF Willamette\_abv Salt Cr nr Oakridge to MF Willamette\_blw NFork | SSARR | 1.5 | 0.1 | 4 | |
| MF Willamette\_blw NFork nr Oakridge to Lookout Point\_IN | Null |  |  |  | |
| Jasper | Middle Fork Willamette | Lookout Point\_OUT to Dexter\_IN | Null |  |  |  | |
| Dexter\_OUT to MF Willamette\_nr Dexter | SSARR | 5 | 0.1 | 2 | |
| MF Willamette\_nr Dexter to MF Willamette+Fall | Null |  |  |  | |
| MF Willamette+Fall to MF Willamette\_at Jasper | Null |  |  |  | |
| Fall Creek | Fall Creek\_OUT to Fall\_blw Winberry Cr nr Fall Creek | SSARR | 5 | 0.1 | 2 | |
| Fall\_blw Winberry Cr nr Fall Creek to Fall\_Mouth | Null |  |  |  | |
| Fall\_Mouth to MF Willamette+Fall | Null |  |  |  | |
| Goshen | Row | Row\_abv Pitcher Cr nr Dorena to Dorena\_IN | Null |  |  |  | |
| Dorena\_OUT to Row\_nr Cottage Grove | SSARR | 6 | 0.1 | 3 | |
| Row\_nr Cottage Grove to Row\_Mouth | Null |  |  |  | |
| Row\_Mouth to CF Willamette+Row | Null |  |  |  | |
| Coast Fork Willamette | Cottage Grove\_OUT to CF Willamette\_blw Cottage Grove Dam | Null |  |  |  | |
| CF Willamette\_blw Cottage Grove Dam to CF Willamette+Row | SSARR | 6 | 0.1 | 3 | |
| CF Willamette+Row to CF Willamette\_nr Goshen | Null |  |  |  | |
| Vida | South Fork McKenzie | Cougar\_OUT to SF McKenzie\_nr Rainbow | SSARR | 4 | 0.2 | 2 | |
| SF McKenzie\_nr Rainbow to SF McKenzie\_Mouth | Null |  |  |  | |
| SF McKenzie\_Mouth to McKenzie+SF McKenzie | Null |  |  |  | |
| Blue River | Blue River\_OUT to Blue\_at Blue River | Null |  |  |  | |
| Blue\_at Blue River to Blue\_Mouth | SSARR | 4 | 0.1 | 2 | |
| Blue\_Mouth to McKenzie+Blue | Null |  |  |  | |
| McKenzie | McKenzie+SF McKenzie to McKenzie+Blue | Null |  |  |  | |
| McKenzie+Blue to McKenzie\_at Vida | MC |  |  |  | |
| Monroe | Long Tom | Fern Ridge\_OUT to Long Tom\_nr Alvadore | Null |  |  |  | |
| Long Tom\_nr Alvadore to Long Tom\_at Monroe | SSARR | 5 | 0.1 | 2 | |
| Foster | Middle Fork Santiam | Green Peter\_OUT to Foster\_IN | SSARR | 2 | 0.1 | 2 | |
| Waterloo | South Santiam | Foster\_OUT to So Santiam+Wiley | Null |  |  |  | |
| So Santiam+Wiley to So Santiam\_nr Foster | Null |  |  |  | |
| So Santiam\_nr Foster to So Santiam\_at Waterloo | SSARR | 4 | 0.1 | 2 | |
| Mehama | North Santiam | Big Cliff\_OUT to No Santiam\_at Niagara | Null |  |  |  | |
| No Santiam\_at Niagara to No Santiam\_at Mehama | SSARR | 6 | 0.1 | 2 | |
| Jefferson | South Santiam | So Santiam\_at Waterloo to Lebanon Div\_IN | Null |  |  |  | |
| Lebanon Div\_IN to So Santiam\_Mouth | SSARR | (see interpolation table) | | 14 | |
| So Santiam\_Mouth to No Santiam+So Santiam | Null |  |  |  | |
| North Santiam | No Santiam\_at Mehama to Stayton Div\_IN | SSARR | (see interpolation table) | | 12 | |
| Stayton Div\_IN to Greens Bridge NR Jefferson | Null |  |  |  | |
| Greens Bridge NR Jefferson to No Santiam\_Mouth | Null |  |  |  | |
| No Santiam\_Mouth to No Santiam+So Santiam | Null |  |  |  | |
| Santiam | No Santiam+So Santiam to Santiam\_at Jefferson | Null |  |  |  | |
| Harrisburg | Coast Fork Willamette | CF Willamette\_nr Goshen to CF Willamette\_Mouth | MC |  |  |  | |
| CF Willamette\_Mouth to MF Willamette+CF Willamette | Null |  |  |  | |
| Middle Fork Willamette | MF Willamette\_at Jasper to MF Willamette\_Mouth | MC |  |  |  | |
| MF Willamette\_Mouth to MF Willamette+CF Willamette | Null |  |  |  | |
| McKenzie | McKenzie\_at Vida to Below Leaburg Dam | SSARR | (see interpolation table) | | 10 | |
| Below Leaburg Dam to McKenzie R. NR Walterville | Null |  |  |  | |
| McKenzie R. NR Walterville to Above Hayden Brige at Springfield | Null |  |  |  | |
| Above Hayden Brige at Springfield to McKenzie\_Mouth | Null |  |  |  | |
| McKenzie\_Mouth to Willamette+McKenzie | Null |  |  |  | |
| Willamette | MF Willamette+CF Willamette to Willamette\_at Eugene | MC |  |  |  | |
| Willamette\_at Eugene to Willamette+McKenzie | Null |  |  |  | |
| Willamette+McKenzie to Willamette\_at Harrisburg | MC | (see notes) | | | |
| Albany | Long Tom | Long Tom\_at Monroe to Long Tom\_Mouth | SSARR | (see interpolation table) | | 9 | |
| Long Tom\_Mouth to Willamette+Long Tom | Null |  |  |  | |
| Willamette | Willamette\_at Harrisburg to Willamette+Long Tom | SSARR | (see interpolation table) | | 5 | |
| Willamette+Long Tom to Willamette+Marys | Null |  |  |  | |
| Willamette+Marys to Willamette+Calapooia | Null |  |  |  | |
| Willamette+Calapooia to Willamette\_at Albany | Null |  |  |  | |
| Salem | Santiam | Santiam\_at Jefferson to Santiam\_Mouth | MC |  |  |  | |
| Santiam\_Mouth to Willamette+Santiam | Null |  |  |  | |
| Willamette | Willamette\_at Albany to Willamette+Santiam | MC |  |  |  | |
| Willamette+Santiam to Willamette+Luckiamute | Null |  |  |  | |
| Willamette+Luckiamute to Willamette+Rickreall | MC |  |  |  | |
| Willamette+Rickreall to Willamette\_at Salem | Null |  |  |  | |
| Notes: |  |  |  |  |  |  |
| "MC" denotes the Muskingum-Cunge 8-point cross-section routing model. | | | |  |  |  |

Table 5. Storage Interpolation Tables used for SSARR routing

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lebanon Div\_IN to So Santiam\_Mouth | | No Santiam\_at Mehama to Stayton Div\_IN | | McKenzie\_at Vida to Below Leaburg Dam | | Long Tom\_at Monroe to Long Tom\_Mouth | | Willamette\_at Harrisburg to Willamette+Long Tom | |
| Outflow (cfs) | Time of Storage (hours) | Outflow (cfs) | Time of Storage (hours) | Outflow (cfs) | Time of Storage (hours) | Outflow (cfs) | Time of Storage (hours) | Outflow (cfs) | Time of Storage (hours) |
| 1 | 1.0000 | 1 | 2.0000 | 1 | 4.4000 | 1 | 4.6100 | 1 | 8.2980 |
| 100 | 0.6310 | 100 | 1.2619 | 50 | 4.2182 | 1000 | 3.8100 | 1000 | 6.8580 |
| 500 | 0.5372 | 500 | 1.0743 | 100 | 3.7275 | 3000 | 3.0600 | 3000 | 5.5080 |
| 1000 | 0.5012 | 1000 | 1.0024 | 500 | 2.6139 | 5000 | 2.8700 | 5000 | 5.1660 |
| 3000 | 0.4490 | 3000 | 0.8981 | 1000 | 2.1103 | 10000 | 2.2500 | 10000 | 4.0500 |
| 5000 | 0.4267 | 5000 | 0.8534 | 4000 | 1.4000 | 20000 | 1.6500 | 20000 | 2.9700 |
| 10000 | 0.4061 | 10000 | 0.8121 | 10000 | 1.1349 | 30000 | 1.5300 | 30000 | 2.7815 |
| 20000 | 0.4272 | 20000 | 0.8543 | 20000 | 1.1976 | 40000 | 1.6700 | 40000 | 3.0962 |
| 30000 | 0.4637 | 30000 | 0.9274 | 30000 | 1.2597 | 50000 | 2.0800 | 50000 | 4.0435 |
| 40000 | 0.4956 | 40000 | 0.9912 | 40000 | 1.4110 | 60000 | 2.5300 | 60000 | 5.1005 |
| 50000 | 0.5253 | 50000 | 1.0507 | 50000 | 1.9434 | 70000 | 2.8400 | 70000 | 5.6232 |
| 60000 | 0.5491 | 60000 | 1.0982 | 60000 | 2.2515 | 80000 | 2.7900 | 80000 | 5.6246 |
| 70000 | 0.5735 | 70000 | 1.1470 | 80000 | 2.3362 | 100000 | 2.6300 | 100000 | 5.5861 |
| 80000 | 0.5821 | 80000 | 1.1641 | 140000 | 1.8047 | 120000 | 2.4200 | 120000 | 5.4014 |
| 100000 | 0.5376 | 100000 | 1.0752 | 180000 | 1.5106 | 150000 | 2.3400 | 150000 | 5.1386 |
| 120000 | 0.4347 | 120000 | 0.8694 | 300000 | 1.3220 | 180000 | 2.2700 | 180000 | 4.9849 |
| 150000 | 0.3340 | 150000 | 0.6681 | 500000 | 1.1504 | 290000 | 2.1300 | 290000 | 4.7925 |
| 180000 | 0.2982 | 180000 | 0.5964 |  |  | 500000 | 2.1300 | 500000 | 4.7925 |
| 290000 | 0.2843 | 290000 | 0.5686 |  |  |  |  |  |  |
| 500000 | 0.2692 | 500000 | 0.5384 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

**Muskingum-Cunge Routings:**

The 8-point Muskingum-Cunge method was selected as the routing method for some reaches in the HEC-ResSim model. Muskingum-Cunge method was selected for various reasons:

* Muskingum Cunge meets all the criteria suggested in Table 9-3 of EM 1110-2-1417 (USACE 1994), and is one of few hydrologic methods that approximates the Diffusion wave equation.
* Muskingum Cunge method recalculates new Muskingum coefficients for every time step in each reach. This is advantageous for Willamette flooding because of the large range of expected flows, which can result in varying storage and attenuation as the stage increases and flood water moves onto the flood plains.
* The 8 point cross section definition allows a user to define the large flood plains that exist in the Willamette basin.

The 8-point cross sections for each reach were extracted from the 1970s FEMA Flood Insurance Study (FIS) HEC-2 models (Lane Co. (1985), Linn Co. (FEMA, 1986), Marion Co. (1979), Clackamas Co. (1978), and Yamhill Co. (1983)). Cross sections in the HEC-2 model were evaluated to identify those which best represented the channel characteristics of the various reaches. The cross sections which best represented the average channel shape, and flood plain extents of the reach were selected. Manning’s n values and stream slopes were also extracted from the HEC-2 models and used as initial values for the routing calibration.

Table 6. Summary of Routing by Reach for Willamette Hourly Model

| Local Sub-Basin | River | Reach Name in HEC-ResSim | Length (ft) | Slope | Channel *n* | Left *n* | Right *n* |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Vida | McKenzie | McKenzie + Blue to McKenzie at Vida | 49100 | 0.002 | 0.035 | 0.12 | 0.12 |
| Harrisburg | Coast Fork Willamette | CF Willamette near Goshen to CF Willamette Mouth | 33790 | 0.0013 | 0.045 | 0.065 | 0.065 |
| Middle Fork Willamette | MF Willamette at Jasper to MF Willamette Mouth | 42240 | 0.0026 | 0.045 | 0.08 | 0.08 |
| Willamette | MF Willamette + CF Willamette to Willamette at Eugene | 80255 | 0.0013 | 0.045 | 0.06 | 0.06 |
| Willamette + McKenzie to Willamette at Harrisburg | 70000 | 0.00078 | 0.045 | 0.10 | 0.10 |
| Salem | Santiam | Santiam at Jefferson to Santiam Mouth | 50790 | 0.00083 | 0.035 | 0.08 | 0.08 |
| Willamette | Willamette at Albany to Willamette + Santiam | 60770 | 0.00025 | 0.03 | 0.08 | 0.08 |
| Willamette + Luckiamute to Willamette + Rickreall | 126187 | 0.00017 | 0.03 | 0.06 | 0.06 |

### Routing in Daily Model (taken from OMET appendix B)

Each river reach must be configured with a routing method which is used by the program to determine how quickly a given quantity of water will move through the reach. The travel time of the water depends on the cross-section (shape and depth) of the river channel and its length. There are a number of methods that can be used for this specification, and the two that were chosen for this study are the SSARR and null routings.

A null routing means that the incoming water instantaneously passes through the reach. All reaches not identified in Table 7 and Table 8 use the null routing. The SSARR routing is based on a timing equation, TS = KTS/Q^n, where the time of storage in the reach is TS, Q is the flow, and KTS and n are parameters determined through hydrologic analyses. TS is computed by the model based on the flow Q in the time step and the parameters KTS and n from the tables below. The SSARR routings for reaches using this method in the model are shown in Table 7. Some additional reaches listed in Table 8 use the interpolation method of SSARR routing. The routing shown in these two tables were used to compute the local flows.

The routings are defined in a way that each reservoir’s flow toward a control point goes through one reach with SSARR routing and all other reaches null routing, but the time to travel through the SSARR designated reach is the same as would physically occur through the entire stretch of SSARR plus null routing. This form of specification reduces the computation time of each simulation. The SSARR routing was used because this method is compatible with a daily time step. Other routing methods, such as the Muskingum-Cunge, are appropriate for hourly time steps but cause the ResSim model problems when using daily time steps. The null routing requires little computation time and so is used where the timing of the flow arrival is not important, such as downstream of control points.

Table 7. Reaches with SSARR Routing in the Res-Sim Model, Time of Storage Method TS=KTS/Q^n.

|  |  |  |  |
| --- | --- | --- | --- |
| Name of Reach | KTS | n | Number of Subreaches |
| Blue\_at Blue River to Blue\_Mouth | 4 | 0.1 | 2 |
| CF Willamette\_blw Cottage Grove Dam to CF Willamette+Row | 6 | 0.1 | 3 |
| CF Willamette\_nr Goshen to CF Willamette\_Mouth | 5.5 | 0.1 | 2 |
| Cougar\_OUT to SF McKenzie\_nr Rainbow | 4 | 0.2 | 2 |
| Dexter\_OUT to MF Willamette\_nr Dexter | 5 | 0.1 | 2 |
| Dorena\_OUT to Row\_nr Cottage Grove | 6 | 0.1 | 3 |
| Fall Creek\_OUT to Fall\_blw Winberry Cr nr Fall Creek | 5 | 0.1 | 2 |
| Green Peter\_OUT to Foster\_IN | 2 | 0.1 | 2 |
| Long Tom\_nr Alvadore to Long Tom\_at Monroe | 5 | 0.1 | 2 |
| MF Willamette\_abv Salt Cr nr Oakridge to MF Willamette\_blw NFork | 1.5 | 0.1 | 4 |
| MF Willamette\_at Jasper to MF Willamette\_Mouth | 5.5 | 0.1 | 2 |
| No Santiam\_at Niagara to No Santiam\_at Mehama | 6 | 0.1 | 2 |
| So Santiam\_nr Foster to So Santiam\_at Waterloo | 4 | 0.1 | 2 |
| \* Reaches not listed in this table have null routings | | | |

Table 8. Reaches with SSARR Routing in the Res-Sim Model Using Interpolation Tables for the Time of Storage Method.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Outflow (cfs) | Time of Storage (hours) for Reach (See Key at Bottom of Table) | | | | | | | |
|  | A | B | C | D | E | F | G | H |
| 1 | 1.0000 | 2.0000 | 4.6100 | 8.2980 | 8.0500 | 4.4000 |  |  |
| 50 |  |  |  |  |  | 4.2182 |  |  |
| 100 | 0.6310 | 1.2619 |  |  |  | 3.7275 |  |  |
| 500 | 0.5372 | 1.0743 |  |  |  | 2.6139 |  |  |
| 1,000 | 0.5012 | 1.0024 | 3.8100 | 6.8580 | 4.9000 | 2.1103 | 4.9500 | 4.9500 |
| 3,000 | 0.4490 | 0.8981 | 3.0600 | 5.5080 |  |  |  |  |
| 4,000 |  |  |  |  |  | 1.4000 |  |  |
| 5,000 | 0.4267 | 0.8534 | 2.8700 | 5.1660 |  |  |  |  |
| 10,000 | 0.4061 | 0.8121 | 2.2500 | 4.0500 | 3.5000 | 1.1349 | 4.0500 | 4.0500 |
| 20,000 | 0.4272 | 0.8543 | 1.6500 | 2.9700 | 2.1000 | 1.1976 | 3.3000 | 3.3000 |
| 30,000 | 0.4637 | 0.9274 | 1.5300 | 2.7815 | 2.1000 | 1.2597 | 2.4000 | 2.4000 |
| 40,000 | 0.4956 | 0.9912 | 1.6700 | 3.0962 | 2.4500 | 1.4110 | 2.1000 | 2.1000 |
| 50,000 | 0.5253 | 1.0507 | 2.0800 | 4.0435 | 3.1500 | 1.9434 | 1.8000 | 1.8000 |
| 60,000 | 0.5491 | 1.0982 | 2.5300 | 5.1005 | 3.8500 | 2.2515 | 1.9500 | 1.9500 |
| 70,000 | 0.5735 | 1.1470 | 2.8400 | 5.6232 |  |  |  |  |
| 80,000 | 0.5821 | 1.1641 | 2.7900 | 5.6246 | 3.8500 | 2.3362 | 2.1000 | 2.1000 |
| 100,000 | 0.5376 | 1.0752 | 2.6300 | 5.5861 |  |  | 3.4500 | 3.4500 |
| 120,000 | 0.4347 | 0.8694 | 2.4200 | 5.4014 |  |  | 4.2000 | 4.2000 |
| 140,000 |  |  |  |  | 3.3600 | 1.8047 | 4.5000 | 4.5000 |
| 150,000 | 0.3340 | 0.6681 | 2.3400 | 5.1386 |  |  |  |  |
| 170,000 |  |  |  |  |  |  | 4.6500 | 4.6500 |
| 180,000 | 0.2982 | 0.5964 | 2.2700 | 4.9849 | 3.3600 | 1.2106 |  |  |
| 200,000 |  |  |  |  |  |  | 4.2000 | 4.2000 |
| 250,000 |  |  |  |  |  |  | 3.3000 | 3.3000 |
| 290,000 | 0.2843 | 0.5686 | 2.1300 | 4.7925 |  |  |  |  |
| 300,000 |  |  |  |  | 3.3600 | 1.3220 | 3.4500 | 3.4500 |
| 400,000 |  |  |  |  |  |  | 3.2800 | 3.2800 |
| 500,000 | 0.2692 | 0.5384 | 2.130 | 4.7925 | 3.3600 | 1.1504 | 3.2800 | 3.2800 |
| 750,000 |  |  |  |  |  |  | 3.2800 | 3.2800 |
| Reach Name | | | | | | | | Key |
| Lebanon Div\_IN to So Santiam\_Mouth | | | | | | | | A |
| No Santiam\_at Mehama to Stayton Div\_IN | | | | | | | | B |
| Long Tom\_at Monroe to Long Tom\_Mouth | | | | | | | | C |
| Willamette\_at Harrisburg to Willamette+Long Tom | | | | | | | | D |
| Willamette\_at Eugene to Willamette+McKenzie | | | | | | | | E |
| McKenzie\_at Vida to Below Leaburg Dam | | | | | | | | F |
| Santiam\_at Jefferson to Santiam\_Mouth | | | | | | | | G |
| Willamette\_at Albany to Willamette+Santiam | | | | | | | | H |
| \*Reaches not listed in this table have null routings. | | | | | | | | |

## Timestep

Talk about how models were combined (WEST ARRA hourly model, conservation season model, Julie’s IRRM model, etc.). Talk about how Cindy made a number of changes to improve the rules.

### Daily

### Hourly

## Physical Attributes

The physical characteristics of the thirteen reservoirs in the Willamette River Basin are input into the Res-Sim model in tables that define capacity. The physical descriptions include the project composite release capacity, the pool characteristics, such as storage and evaporation, and the outlets of the dam, such as spillways, controlled outlets, and power plants. The physical parameters cannot be violated within ResSim; however reservoir operating rules can shape how outlets are used. For example, Detroit Dam has lower regulating outlets that have not been used for many years because of cavitation damage, but its flow capacity as a function of reservoir elevation is still given in the physical description tables for the project. To prevent the model from sending flow through this outlet, the operation set for Detroit has a rule that specifies the maximum flow through this outlet is zero. To analyze an operational measure requiring flow through this outlet (assuming the cavitation damage would be repaired and prevented), a rule would then specify a non-zero maximum, while the physical description of the outlet capacity would stay the same.

The various spillway gates and regulating outlets have mechanical or structural limitations that should be captured in the model. The tainter gates at some of the Willamette have been found to have some structural issues. For these dams there are Interim Risk Reduction Measures (IRRM) in place. The model captures these IRRMs in rule sets which will be discussed in a later section. Most of the gates have minimum allowable gate openings which need to be specified in the physical characteristics. This minimum opening is sometimes required to prevent vibrations in the gate mechanism or to prevent cavitation damage. Each of these gate restrictions or operation limits are described in the model.

### Evaporation

Table 9 lists the monthly total evaporation in inches from twelve reservoirs. Big Cliff reservoir is a run of river dam with the water behind it essentially still a river, so no evaporation is specified for it. **Error! Reference source not found.** and others in this section all refer to the projects by their three letter code:

DET = Detroit BCL = Big Cliff FOS = Foster GPR = Green Peter

FRN = Fern Basin BLU = Blue River CGR = Cougar

DOR = Dorena COT = Cottage Grove FAL = Fall Creek

HCR = Hills Creek LOP = Lookout Point DEX = Dexter

Table 9. Monthly Total Evaporation for Willamette Basin Reservoirs.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Month | Monthly Total Evaporation, in Inches, for Each Reservoir (None for Big Cliff) | | | | | | | | | | | |
|  | DET | FOS | GPR | FRN | BLU | CGR | DOR | COT | FAL | HCR | LOP | DEX |
| Jan | -12.79 | -12.79 | -12.79 | -6.10 | -6.24 | -6.24 | -6.67 | -7.07 | -6.24 | -6.24 | -6.24 | -6.24 |
| Feb | -8.83 | -8.83 | -8.83 | -4.19 | -3.03 | -3.03 | -4.07 | -4.23 | -3.03 | -3.03 | -3.03 | -3.03 |
| Mar | -7.95 | -7.95 | -7.95 | -2.41 | -2.62 | -2.62 | -3.28 | -3.25 | -2.62 | -2.62 | -2.62 | -2.62 |
| Apr | -4.66 | -4.66 | -4.66 | 0.67 | -0.77 | -0.77 | -0.90 | -0.72 | -0.77 | -0.77 | -0.77 | -0.77 |
| May | -0.95 | -0.95 | -0.95 | 3.25 | 1.29 | 1.29 | 1.81 | 1.67 | 1.29 | 1.29 | 1.29 | 1.29 |
| Jun | 2.51 | 2.51 | 2.51 | 5.01 | 3.77 | 3.77 | 4.32 | 3.93 | 3.77 | 3.77 | 3.77 | 3.77 |
| Jul | 6.86 | 6.86 | 6.86 | 7.75 | 7.09 | 7.09 | 7.67 | 7.24 | 7.09 | 7.09 | 7.09 | 7.09 |
| Aug | 5.26 | 5.26 | 5.26 | 6.52 | 5.96 | 5.96 | 6.27 | 5.87 | 5.96 | 5.96 | 5.96 | 5.96 |
| Sep | 1.17 | 1.17 | 1.17 | 3.61 | 2.81 | 2.81 | 3.01 | 2.95 | 2.81 | 2.81 | 2.81 | 2.81 |
| Oct | -4.87 | -4.87 | -4.87 | -0.89 | -1.42 | -1.42 | -1.77 | -2.06 | -1.42 | -1.42 | -1.42 | -1.42 |
| Nov | -12.67 | -12.67 | -12.67 | -5.94 | -5.65 | -5.65 | -6.82 | -6.40 | -5.65 | -5.65 | -5.65 | -5.65 |
| Dec | -14.14 | -14.14 | -14.14 | -6.91 | -6.94 | -6.94 | -7.32 | -7.48 | -6.94 | -6.94 | -6.94 | -6.94 |

# Flood Control Concepts (currently written for Willamette FIS)

Basic Rules for Projects (hourly and daily models)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Rule | Same Rule hourly/daily | Unique for Hourly | Unique for Daily |
| **Flood Control Zone** | | | | |
|  | Induced Surcharge |  | X | X |
|  | | | | |
| **Conservation Zone** | | | | |
|  | Max Power Release\* | X |  |  |
|  | Min Conservation Flow | X |  |  |
|  | Max Conservation Flow | X |  |  |
|  | Ramp Up |  | X | X |
|  | Ramp Down |  | X | X |
|  | Power Guide Curve\* | X |  |  |
|  | D/S Augmentation Rules | X |  |  |
|  | D/S Bankfull Rules | X |  |  |
| **Buffer Zone** | | | | |
|  | Max Power Release\* | X |  |  |
|  | Min Conservation Flow | X |  |  |
|  | Ramp Down |  | X | X |
|  | Power Guide Curve\* | X |  |  |
|  |  |  |  |  |

## Use of Reservoir Zones

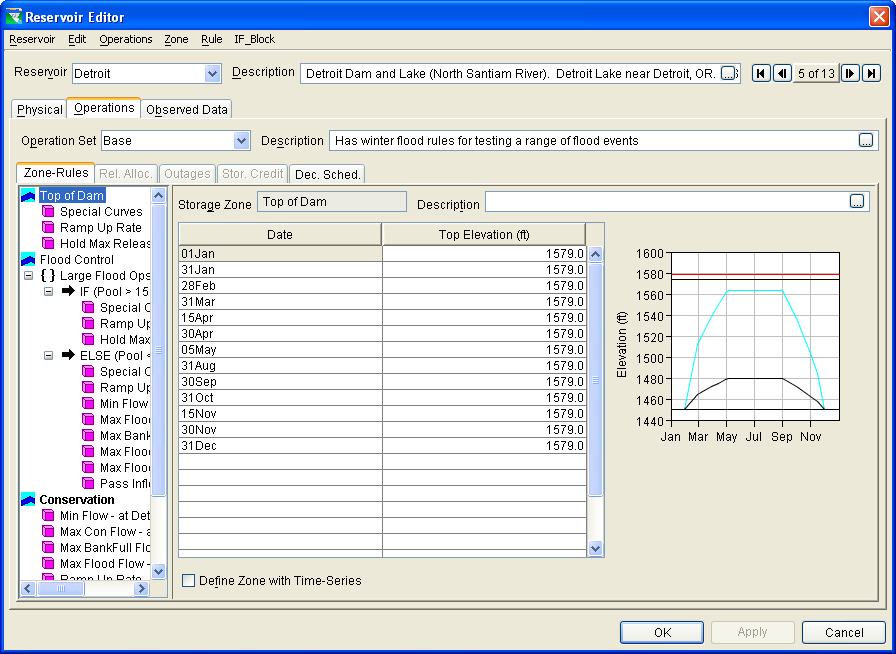
Within ResSim the Willamette reservoirs are broken into zones where specific rules can be applied. The rules for a specific zone are applied when the modeled reservoir elevation is at, or below, that zone. Generally they are applied as described below in and are shown graphically in **Figure 2**:

**Table 10**. Zones used in Willamette ResSim Model

|  |  |
| --- | --- |
| **Zone Name** | **Significance** |
| Top of Dam | The top of the dam where overtopping would occur |
| Flood Control | Max pool available for flood control |
| 50% FC Pool\* | Used to separate the flood control storage into two types of flood control operations: normal and aggressive |
| Primary Flood Control\* |
| Secondary Flood Control\* |
| Conservation | The “Rule Curve” which includes minimum and maximum conservation pools |
| Buffer | Acts like an interim draft limit to keep pool from drafting too low below minimum conservation pool |
| Inactive | The lowest pool that can access outlets |

\* Not used for all projects

**Figure 2. Typical graph of Reservoir Zones**



## Operational Rules

### Special Curves

Special curves are used throughout the Willamette Basin to provide guidance for storing the largest flood events that threaten to overfill the reservoir. Outflows from the projects are determined from the current pool elevation and the inflow rate to utilize the remaining storage and prevent filling and passing the peak inflows from an event. ResSim utilizes a built-in *Induced Surcharge Rule* to simulate this operation. Each project is unique in how special curves are applied and factor in the following:

* Inflows (averaged over a specific period or lagged)
* Outlet capacity (controlled vs uncontrolled)
* Time of Storage (basin specific)
* Outflows during recession (maintain peak, pass inflow or is dependent on downstream conditions)

Each projects configuration for special curves is documented below in Section 3.

### Downstream Control Points

Each storage project in the Willamette is operated for at least one control point downstream (sometimes more). Each control point has two key regulation thresholds: *bankfull* and *flood stage*. Typically projects are operated to maintain flows below *bankfull* level, which is a non-damaging level. In larger events, or events with high local flow components, projects are operated to maintain control points below *flood stage*.

During the evacuation period, when a project is drafting out the water stored during a flood, typically the main goal is to make sure the downstream gages remain below these key thresholds and below the peak seen during the event. Specific control point information used in ResSim is described below in \_\_\_\_\_.

Expand here

### Rates of Decrease/Increase

Each project has ramping rates for increasing and decreasing flows. These differ depending on the circumstances, for instance there are BiOp ramp rates for aquatic species, normal WCM ramp rates for human health and safety and high flow ramp rates for emergencies or flood damage reduction operations. The ResSim model has these incorporated for each project and they are prioritized within each zone. Specific rates of increase and decrease used in ResSim are described below in \_\_\_\_\_\_.

### Evacuation Rates

Once flood waters have receded project will need to evacuate the stored flood water. In the majority of flood events, this is done at the *normal evacuation rate*. For larger events, or when the project is fuller, it can be done at the *maximum evacuation rate*. Some projects also have designated primary and secondary storage. The WCM may specify that water is only evacuated using the turbine capacity when below the secondary storage. Specifics for evacuation rates are described below in \_\_\_\_\_\_.

# Model Specifics

## Outlets

Each group of outlets for each project is defined in the ResSim model. A rating capacity curve has been entered for each outlet group. A summary of outlets is shown below in **Table 11**.

**Table 11. Summary of Outlets by Project**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Project** | **Number of Outlets** | | | |
| **Turbines** | **Regulating Outlets** | **Spillway** | |
| **Gated Bays** | **Uncontrolled** |
| **Hills Creek** | 2 | 2 | 3 | - |
| **Lookout Point** | 3 | 4 | 5 | - |
| **Dexter** | 1 | - | 7 | - |
| **Fall Creek** | - | 2 | 2 | - |
| **Cottage Grove** | - | 3 | - | 1 |
| **Dorena** | - | 5 | - | 1 |
| **Cougar** | - | 2 | 2 | - |
| **Blue River** | - | 2 | 2 | - |
| **Fern Ridge** | - | 4 | 1 | - |
| **Green Peter** | 2 | 2 | 2 | - |
| **Foster** | 2 | - | 4 | - |
| **Detroit** | 2 | 4 | 6 | - |
| **Big Cliff** | 1 | - | 3 | - |

## Zones

Key elevations used to mark the ResSim Zones are summarized below in **Table 12**.

**Table 12. Summary of Elevation Zones by Project**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Project** | Top of Dam | Full Pool | Conservation | Buffer | Inactive |
| **Hills Creek** | 1548.0 | 1543.0 | Flood Control Rule Curve |  | 1414.0 |
| **Lookout Point** | 941.0 | 934.0 |  | 819.0 |
| **Dexter** | 702.5 | 697.4 |  | 660.0 \* |
| **Fall Creek** | 839.0 | 834.0 |  | 673.0 |
| **Cottage Grove** |  | 802.6 |  | 719.0 |
| **Dorena** | 865.0 | 860.0 |  | 735.0 |
| **Cougar** | 1705.0 | 1699.0 |  | 1516.0 |
| **Blue River** | 1362.0 | 1357.0 |  | 1132.0 |
| **Fern Ridge** |  | 375.1 |  | 340.0 |
| **Green Peter** | 1020.0 | 1015.0 |  | 887.0 |
| **Foster** |  | 641.0 |  | 596.8 \* |
| **Detroit** | 1579.0 | 1574.0 |  | 1425.0 |
| **Big Cliff** | 1212.0 | 1210.0 |  | 1161.5 \* |

\* Spillway crest

## Flood Operations

### Rate of Increase and Decrease

### Special Curves

### Special Curves

**Table 13. Special Curve Operations by Project for ResSim**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Project** | **Inflow Options** | **Time of Recession (hrs)** | **Max Capacity of Outlets** | **Operation after Peak** | **Falling Pool Options** | **Frequency of Flow Changes** |
| **Hills Creek** |  |  |  | Balance with LOP | Time for Pool Decrease: 5 hrs | 3 hrs |
| **Lookout Point** | Based on the average flows for the previous 2 hours (lagged by 1 hr) |  |  | WCM: Use engineering judgment based on local and system flooding, ability to make future releases and structural integrity of project.  ResSim: Once reservoir stops filling, pass inflow until downstream control points have receded below targets |  |
| **Fall Creek** | WCM/ResSim:  Based on the average flows for the previous 3 hours (lagged by 1 hr) | 19 |  | Once reservoir stops filling, pass inflow until downstream control points have receded below bank full | ResSim: hourly |
| **Cottage Grove** | WCM/ResSim: Based on the average flows for the previous 3 hours (lagged by 1 hr) | 30 |  |  |  |
| **Dorena** | WCM/ResSim: Based on the average flows for the previous 3 hours (lagged by 1 hr) | 28.8 |  | WCM: Maintain peak RO gate opening (even if it’s zero) until flow falls below 5,000 cfs then maintain 5,000 cfs to draft. If max Q is under 5,000 cfs then maintain gate opening until pool drops below spillway crest.  ResSim: Maintain peak gate opening until pool falls below Spillway Crest (835’) | WCM: Every 2 hours  ResSim: Hourly |
| **Cougar** | WCM/ResSim: Based on the average flows for the previous 3 hours (lagged by 1 hr) | 15.4 |  | Pass inflow until there is room downstream to evacuate | WCM: Every 2 hours  ResSim: Hourly |
| **Blue River** | WCM/ResSim: Based on the average flows for the previous 2 hours (lagged by 1 hr) | 15.8 |  | Once reservoir stops filling, pass inflow until downstream control points have receded below bank full | WCM: Every 2 hrs for decrease; Hourly for increase  ResSim: hourly |
| **Fern Ridge** | WCM/ResSim: Based on the average flows for the previous 3 hours (lagged by 1 hr) | 27 |  | Once reservoir stops filling, pass inflow until downstream control points have receded below bank full | WCM/ResSim: Hourly |
| **Green Peter** | WCM/ResSim: Based on the average flows for the previous 3 hours (lagged by 1 hr) | 17.1 |  | Once pool starts to fall pass inflow until WTLO, JFFO have receded below bankfull. Evacuate FOS first. | ResSim: Hourly |
| **Foster** | WCM/ResSim: Based on Previous Hour | 16 |  | Evacuate FOS before GPR but not until WTLO and JFFO have receded below bankfull | WCM:2 hours  ResSim: hourly |
| **Detroit** | WCM/ResSim:  Based on the average flows for the previous 3 hours (lagged by 1 hr) | 23.3 | Turbine, RO and Spillway – All Controlled | Once reservoir starts to fall, maintain current *gate opening* until the reservoir recedes to 1569’ then release the greater of inflow or maximum evacuation rate while maintaining downstream control points below bankfull (MEHO, JFFO and SLMO) | ResSim: hourly |

### Rate of Increase and Decrease

Foster MAX increase: Normal Max/hr = 1500; limiting max/hr = 2500

HCR MAX Increase: 1500 cfs/hr

**Table 14. Rates of Increase and Decrease by Project**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | High Flow Periods (i.e. FDR Operations) | | | | | Normal Operations | | |
|  | Rate of Increase | | | Rate of decrease | |  |  |  |
| **Project** | Normal per Hour | Maximum | | Normal per Hour | Maximum | Normal | Maximum |  |
| per Hour | Per Day |
| **Hills Creek** |  |  |  |  |  |  |  |  |
| **Lookout Point (Dexter)** |  |  |  |  |  |  |  |  |
| **Fall Creek** |  |  |  |  |  |  |  |  |
| **Cottage Grove** |  |  |  |  |  | 100 cfs/hr up | 300 cfs/day max |  |
| **Dorena** |  |  |  |  |  |  |  |  |
| **Cougar** |  |  |  |  |  |  |  |  |
| **Blue River** | <100 cfs 50\*  100-500 cfs 100\*  500-1000 cfs 200\*  1000-2000 cfs 400  >2000 cfs 600  \* 30 Minute Changes | 600 | Na | 30% | na | Na | Na |  |
| **Fern Ridge** |  |  |  |  |  |  |  |  |
| **Green Peter** |  |  |  |  |  |  |  |  |
| **Foster** |  |  |  |  |  |  |  |  |
| **Big Cliff (Detroit)** | 100-1000 cfs 500  1000-3000 cfs 1000  3000-17000 cfs 1500 | 2000 | na | na | na | Tailwater change of 0.3 ft/hr and 0.5 ft/day (increase and decrease) | Tailwater change of 0.3 ft/hr and 0.9 ft/day (increase and decrease) |  |

### Operation for Downstream Control Points

The Willamette projects are operated as a system for flood control. In ResSim the compute time increases greatly if several projects are used to regulate for a single downstream control point. All key control points on each tributary (Vida, Jasper, Goshen, Monroe, Waterloo and Mehama) are regulated by the appropriate project upstream, in the model. For mainstem control points, the southern projects are operated for a common bottleneck point, Harrisburg, and the northern Santiam projects are used to reduce flows at Salem. By reducing for Harrisburg, the southern projects also reduce Salem without slowing the model. Table 15 summarizes which projects are used to reduce stages at each control point.

**Table 15. Project Operation for Control Points**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Control Point | Hills Creek | Lookout Point | Fall Creek | Cottage Grove | Dorena | Cougar | Blue River | Fern Ridge | Green Peter | Foster | Detroit |
| Jasper | **√** | **√** | **√** |  |  |  |  |  |  |  |  |
| Goshen |  |  |  | **√** | **√** |  |  |  |  |  |  |
| Vida |  |  |  |  |  | **√** | **√** |  |  |  |  |
| Harrisburg | **√** | **√** | **√** | **√** | **√** | **√** | **√** |  |  |  |  |
| Monroe |  |  |  |  |  |  |  | **√** |  |  |  |
| Albany | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** |  |  |  |
| Waterloo |  |  |  |  |  |  |  |  | **√** | **√** |  |
| Mehama |  |  |  |  |  |  |  |  |  |  | **√** |
| Jefferson |  |  |  |  |  |  |  |  | **√** | **√** | **√** |
| Salem | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** |

**√** Project uses ResSim rules to reduce stages at the downstream control point.

**√** Project does not use a specific ResSim rule to reduce stages at the downstream control point, but reductions upstream do translate to reduced flows at these control points.

A project cannot always be operated to meet a bankfull goal at a control point. If the project is getting full the downstream control point goal may be higher in order to slow the rate of fill. In ResSim some control point targets are varied depending on the storage of an upstream reservoir. These are summarized below by control point with *ResSim rule names in italics*.

**Mehama, North Santiam River**

* Bankfull (*Max Bankfull Flow – at Mehama*) – Detroit Dam regulates for a bankfull level of 17,000 cfs primarily after a Special Curve operation. The WCM specifies that the evacuation of stored water doesn’t take place until flows downstream recede below banks.
* Varying Target (*Max Flood Flow – at Mehama*) – In most cases the Mehama target is a function of the Detroit Elevation as shown in **Table 16.** Table 16. This rule allows the project to operate more aggressively for flood control when the pool is low and storage is plentiful and to increase releases during the larger floods when the projects are fuller.

**Table 16. Mehama Max Flood Flows**

|  |  |
| --- | --- |
| Detroit Elevation (ft) | Mehama Max Flow (cfs) |
| 1424.0 | 17,000 (bankfull) |
| 1436.0 | 17,000 (bankfull) |
| 1546.0 | 35,000 (flood stage) |
| 1574.0 | 35,000 (flood stage) |

**Waterloo, South Santiam River**

* Bankfull (*Max Bankfull Flow – at Waterloo*) – Green Peter Dam regulates for a bankfull level of 18,000 cfs at Waterloo. Typically this rule does not drive the operation at Green Peter because flows at Jefferson are usually reaching key threshold levels long before this control point.

**Jefferson, Santiam River**

* Bankfull (*Max Bankfull Flow – at Jefferson*) – Detroit Dam regulates for a bankfull level of 35,000 cfs primarily after a Special Curve operation. The WCM specifies that the evacuation of stored water doesn’t take place until flows downstream recede below banks.
* Varying Target (*Max Flood Flow – at Jefferson*) – In most cases the Jefferson target is a function of the Detroit Elevation as shown in **Table 16.** Table 17. This rule allows both Green Peter and Detroit Dams to operate more aggressively for flood control when the pool is low and storage is plentiful and to increase releases during the larger floods when the projects are fuller.

**Table 17. Jefferson Max Flood Flows**

|  |  |
| --- | --- |
| Detroit Elevation (ft) | Jefferson Max Flow (cfs) |
| 1424.0 | 35,000 (bankfull) |
| 1436.0 | 35,000 (bankfull) |
| 1546.0 | 50,000 (flood stage) |
| 1574.0 | 50,000 (flood stage) |

**Salem, Willamette River**

* Bankfull (*Max Bankfull Flow – at Salem*) – Detroit Dam regulates for a bankfull level of 90,000 cfs primarily after a Special Curve operation. The WCM specifies that the evacuation of stored water doesn’t take place until flows downstream recede below banks.
* Varying Target (*Max Flood Flow – at Salem*) – In most cases the Salem target is a function of the Detroit Elevation as shown in **Table 16.** Table 18. This rule allows Detroit to operate more aggressively for flood control when the pool is low and storage is plentiful and to increase releases during the larger floods when the projects are fuller. Green Peter does not actually use this rule in ResSim because the flood control operation in conjunction with Foster is relatively constrained and Green Peter is typically reduced to minimum for Foster.

**Table 18. Salem Max Flood Flows**

|  |  |
| --- | --- |
| Detroit Elevation (ft) | Salem Max Flow (cfs) |
| 1424.0 | 90,000 (bankfull) |
| 1436.0 | 90,000 (bankfull) |
| 1546.0 | 150,000 (flood stage) |
| 1574.0 | 150,000 (flood stage) |

**Vida, McKenzie River**

* Bankfull (*Flood Regulation Goal at Vida*) – Both Cougar and Blue River dams regulate for a bankfull level of 14,500 cfs at Vida. .

**Jasper, Middle Fork Willamette River**

* Bankfull (*Max Bankfull Flow – at Jasper*) – Both Lookout Point and Fall Creek dams regulate for a bankfull level of 20,000 cfs at Jasper. At Lookout Point this rule is in place when the project is below Secondary Flood Control pool. At Fall Creek this rule is in place when the project is below the 50% flood control pool.
* Flood Stage (Max Flood Flow – at Jasper) – When in the upper ranges of their pools (above Secondary Flood Control pool at Lookout Point and above 50% flood control pool at Fall Creek) the projects operate for a flood regulation goal of 22,000 cfs at Jasper.

### Operation for Downstream Control Points

### Evacuation Rates

Each project has a normal and maximum evacuation rate. In ResSim the evacuation rate was set as a function of the pool elevation and is summarized below in \_\_.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Normal | Maximum |  |
| **Hills Creek** |  |  |  |
| **Lookout Point** |  |  |  |
| **Dexter** |  |  |  |
| **Fall Creek** |  |  |  |
| **Cottage Grove** |  |  |  |
| **Dorena** |  |  |  |
| **Cougar** |  |  |  |
| **Blue River** |  | 3700 |  |
| **Fern Ridge** |  |  |  |
| **Green Peter** |  |  |  |
| **Foster** |  |  |  |
| **Detroit** | 10000 | 17000 |  |
| **Big Cliff** |  |  |  |