

## **Workshop 7 – Hydropower: Adding Power Plants and Generating Power (Solution)**

### **Introduction**

In this workshop, you will add the power plant to Crazy Mountain Dam with its existing regulating outlet and estimate the power generation available with reservoir simulation. The addition of a power plant will provide new simulation output, including power capability and generation. The workshop consists of three parts.

In Part A, the objective will be to add the physical power plant with no operational power generation requirements and analyze the simulation results with power generation being incidental to operational release requirements.

In Part B, the objective will be to add operational power requirements and analyze the results of the simulation operating to meet a power schedule.

In Part C, the objective will be to add operational outlet allocation to direct all flow through the power plant.

### ➤ **Part A - Add Physical Power Plant and Produce Incidental Power**

#### **Problem Description**

Part A will focus on the power plant physical features, using the simpler options. Power generated by the power plant will be incidental to the releases derived from non-power releases. The *Crazy Mountain Reservoir Regulation Manual* (Hypothetical Reservoir Manual prepared for this class) contains power plant characteristics in its "*PERTINENT DATA*" section and penstock physical characteristics in Table A-6. You will add the power plant and penstock physical characteristics to the Crazy Mountain reservoir model.

#### **Tasks**

1. Open the hydropower workshop watershed: **WS7\_Start**
2. Select the **Network** module
3. Open the **Reservoir Network "Hydropower Workshop"**
4. Edit the Crazy Mountain reservoir properties
5. Select the **Physical** tab in the Reservoir Editor

- **Section 1 - Adding a Power Plant at Crazy Mountain Dam**

1. Add the Power Plant to the **Dam** level of the Crazy Mountain physical tree.
  - Add the penstock rating in the **Outlet** tab of the new power plant using the data in Table A-6 of the *Crazy Mountain Regulation Manual* or by copy-paste from the "WS#7 Hydropower" sheet of the *CrazyMountainData.xls* Excel file
  - Fill in the Power Plant parameters on the remaining tab panels with labels **Capacity, Efficiency, Station Use**, and **Hyd. Losses** using information from the reservoir regulation manual pertinent data or copy-paste from the Excel file
2. Add Tailwater Elevation to the Power Plant by right-clicking on it in the Physical tree
 

Enter a constant Tailwater Elevation from information provided in the reservoir regulation manual pertinent data.
3. Examine the existing **Operation** rules in Operation Set named "**Hydropower**". What minimum release will be made when:
  - the pool elevation is within the drought contingency zone? 100 CFS
  - the pool elevation is within in the conservation zone? 1,600 CFS
  - the pool elevation is at the top of the conservation zone? Inflow
4. Save the **Hydropower** network.
5. Edit the **Hydropower** alternative.
  - For the configuration named "Existing", select **Hydropower** alternative and then select the **Lookback** tab.
  - The lookback period should have a starting elevation of 662.1 (one tenth foot above drought contingency zone), a constant flow of 1600 cfs through the regulated outlet, and a zero flow through the uncontrolled spillway.
  - Add a constant **zero flow** through the **new power plant**.
  - **Save** the **Hydropower** alternative.
  - **Close** the alternative editor.
6. **Save** the Watershed.

- **Section 2 - Run the reservoir simulation**

1. Select the **Simulation** module.
2. Open the **1997 Spring Freshet** simulation.
3. For the **Hydropower** alternative, select "**Replace From Base Directory ...**" to load the reservoir network data into the simulation alternative. Click to add a check in the **Restore Data** box and click **OK** to complete the replace from base.

4. **Compute the Hydropower alternative.**
5. When the simulation is complete, review the message output in the compute window to verify that the simulation computed successfully. (If the compute is not successful, ask for assistance before continuing.) Click the **Close** button to continue the workshop.

- **Section 3 - Become familiar with the power output options**

1. Point at the Crazy Mountain reservoir in display area (within the simulation module) and right click to bring up the short cut menu. On the context menu select the **Plot Power** option.
2. Select the **Tabulate** from the plot **File** menu to see the tabulation.
3. From the simulation module **Reports** menu select the **Power Summary**.
4. Using the power output options and other outputs such as the **Release Decision Report** and the Reservoir Summary Report, view and analyze the results...

**Questions**

I) What were the minimum and maximum pool elevations in the simulation?  
*Minimum Pool Elevation = 662.1 feet, Maximum Pool Elevation = 683.0 feet.*

II) What was the average power generated?  
*Generated = 5.48 MW, Average Energy = 5.45 MWh*

III) When did the release from the reservoir increase over minimum?  
*On 22 June 1997 at 14:00 hours, when the pool elevation first reached the top of conservation zone.*

Date-Time	Active Zone Elev (ft)	Net Inflow (cfs)	Crazy Mountain Active Rule Flow (cfs)	-Dam Active Rule Flow (cfs)	-Dam L&O Uncontrolled Flow (cfs)	-Controlled Outlet Active Rule Flow (cfs)	-Uncontrolled Outlet Uncontrolled Flow (cfs)	-Power Plant Active Rule Flow (cfs)
22Jun1997, 12:00	682.60	9,396.90	1,600.00	1,600.00	0.00	800.00	0.00	800.00
22Jun1997, 13:00	682.79	9,553.82	1,600.00	1,600.00	0.00	800.00	0.00	800.00
22Jun1997, 14:00	682.94	9,686.26	4,781.38	4,781.38	0.00	2,390.69	0.00	2,390.69
22Jun1997, 15:00	683.00	9,782.97	9,782.97	9,782.97	0.00	4,891.49	0.00	4,891.49
22Jun1997, 16:00	683.00	9,833.60	9,833.60	9,833.60	0.00	4,916.80	0.00	4,916.80
22Jun1997, 17:00	683.00	9,831.18	9,831.18	9,831.18	0.00	4,915.59	0.00	4,915.59
22Jun1997, 18:00	683.00	9,774.04	9,774.04	9,774.04	0.00	4,887.02	0.00	4,887.02
22Jun1997, 19:00	683.00	9,666.43	9,666.43	9,666.43	0.00	4,833.21	0.00	4,833.21
22Jun1997, 20:00	683.00	9,518.03	9,518.03	9,518.03	0.00	4,759.01	0.00	4,759.01
22Jun1997, 21:00	683.00	9,342.39	9,342.39	9,342.39	0.00	4,671.19	0.00	4,671.19
22Jun1997, 22:00	683.00	9,154.83	9,154.83	9,154.83	0.00	4,577.42	0.00	4,577.42
22Jun1997, 23:00	683.00	8,970.16	8,970.16	8,970.16	0.00	4,485.08	0.00	4,485.08

IV) What rule determined the increase above minimum?

*The "GC" rule determined the release, setting the release to just fill to top of conservation, and thereafter set the release to inflow to maintain the pool at top of conservation.*

V) What is the maximum power that could have been generated when the pool was at the top of the conservation zone?

*35.341 MW was the maximum power capability, when the headwater was the top of the conservation zone.*

VI) What was the maximum power actually generated?

*The maximum of 15.861 MW was generated on 26 June 1997 @ 0600 hours.*

Hydropower Production Report								
Power Surpluses and Shortages								
EOP Date/Time	Power Generated MW	Plant Capability MW	Required Schedule	Energy Generated	Energy Scheduled MWh	Energy Generated During Schedule MWh	Energy Surplus to Schedule MWh	Energy Shortage During Schedule MWh
Wed 25Jun1997, 22:00	15.443	35.341						
Wed 25Jun1997, 23:00	15.551	35.341						
Wed 25Jun1997, 24:00	15.640	35.341						
Thu 26Jun1997, 01:00	15.712	35.341						
Thu 26Jun1997, 02:00	15.767	35.341						
Thu 26Jun1997, 03:00	15.808	35.341						
Thu 26Jun1997, 04:00	15.837	35.341						
Thu 26Jun1997, 05:00	15.854	35.341						
Thu 26Jun1997, 06:00	15.861	35.341						
Thu 26Jun1997, 07:00	15.860	35.341						
Thu 26Jun1997, 08:00	15.854	35.341						
Thu 26Jun1997, 09:00	15.842	35.341						
Thu 26Jun1997, 10:00	15.826	35.341						
Thu 26Jun1997, 11:00	15.807	35.341						
Thu 26Jun1997, 12:00	15.785	35.341						
Thu 26Jun1997, 13:00	15.761	35.341						
Thu 26Jun1997, 14:00	15.736	35.341						
Thu 26Jun1997, 15:00	15.708	35.341						
Thu 26Jun1997, 16:00	15.679	35.341						
Thu 26Jun1997, 17:00	15.648	35.341						
Thu 26Jun1997, 18:00	15.615	35.341						

VII) Was the power plant flow the same as the total outflow from the reservoir? If not, why was it different?

*No, approximately half the flow was released through the power plant and half the flow was released through the regulated outlet. This happens because default outlet release allocation is for balanced release among outlets.*

➤ Part B –Operating Rule: Hydropower - Schedule

**Problem Description**

In this part, you will add a hydropower energy requirement rule to the reservoir and evaluate the ability to meet this requirement with reservoir simulation. You will specify a scheduled energy rule and run the simulation. Power generated by the power plant in Part B will be based on a monthly energy requirement. The addition of power rules will provide new output for required power generation, which you will observe and analyze in the simulation.

*Table 3-1 from the Crazy Mountain Reservoir Regulation Manual lists the monthly energy required from the Crazy Mountain power plant to be generated on a schedule of 4 hours per day Monday through Friday, 0600-1000 hours. Your job is to identify the power operation requirements in the regulation manual and add them as a rule to the Crazy Mountain reservoir.*

**Tasks** (continued from Part A)

5. Close all plots, tables, and reports you may have opened in the Simulation Module, then go the Network module and open the **Reservoir Network “Hydropower Workshop”**
  6. Bring up the **Reservoir Editor** for Crazy Mountain reservoir
  7. Select the **Operations** tab in Reservoir Editor
  8. Select the **Hydropower** Operation Set.
- **Section 1 - Adding a Scheduled Energy Operation Rule at Crazy Mountain Dam**
    9. Add the **Firm Energy** rule to the reservoir's **Conservation Zone**.
      - On the **New Operating Rule** dialog select the **Crazy Mountain-Power Plant** from the dropdown list in the **Operates Release from:** field.
      - Select the **Hydropower - Schedule** rule from the dropdown list in the **Rule Type:** field.
      - Type **Scheduled Power** (or any label meaningful to you) in the **Rule Name** field to name the rule and click **OK**.

10. Add the scheduled energy information shown in the *Table 3-1* in Section III (Water Control Plan) of the *Crazy Mountain Reservoir Regulation Manual*. Optionally, you may copy the same data from the Excel file, *CrazyMountainData.xls* under the worksheet labeled “*WS#7 Hydropower*” and paste them into the ResSim rule tables.
- Edit the **Scheduled Power** rule in the **Conservation Zone**.
  - Select the “**Options...**” button to bring up the **Power Generation Requirement** dialog.
  - As noted in Table 3-1, the energy *Requirement Varies Monthly* and is specified as **Monthly Total MWH**. For this workshop, allow the period over which the generation requirement is satisfied to be **Each Time-Step**.
  - Close the **Power Generation Requirement** dialog by clicking **OK**.
  - Fill in the **Monthly Requirement (MWh)** from *Table 3-1* or by a copy-paste from the table in the Excel file.
  - Click the “**Power Generation Pattern ...**” button to bring up the **Power Generation Pattern** dialog.
  - At top of the **Power Generation Pattern** dialog, the **Seasonal Variation** check box should remain unchecked and the label below it should read “**Pattern Applies all Year**” to allow the same pattern to apply throughout the simulation period.
  - Since the regulation manual specifies a Monday through Friday schedule, select the **Weekdays and Weekend** pattern in the “**Specify Pattern for**” field.
  - Enter “**1.0**” as the proportional pattern weighting factor for each of the four hours indicated for **Weekdays** in the regulation manual and excel worksheet. The weighting factor could be any number, but must be of equal magnitude for the four hours to indicate an equally weighted pattern. The remainder of weekday hours and the weekend should be zeros to indicate no generation required in those periods. Alternately, the pattern may be entered more conveniently with a copy-paste from the table in the Excel file.
  - Close the **Power Generation Pattern** dialog with an **OK**.
  - Add the new **Scheduled Power** rule to the **Drought Contingency** zone by selecting **Use Existing** from the **Rule** menu.

### Question

VIII) How much energy will your new scheduled power rule attempt to generate during the month of June? 2500 MWh

11. Close the reservoir editor and **Save** the **Network**.
12. **Save** the Watershed from the **File** menu.
- **Section 2 - Run the reservoir simulation**
13. Select the **Simulation** module.
14. Open the **1997 Spring Freshet** simulation.

15. For the **Hydropower** alternative, select “**Replace From Base Directory ...**” to load the reservoir network data into the simulation alternative. Click to add a check in the **Restore Data** box and click **OK** to complete the replace from base.
16. **Compute** the **Hydropower** alternative.
17. Click **Close** on the **Compute** dialog when the simulation is complete.
- **Section 3 - Analyze the scheduled power simulation by examining the power output options**
  18. Examine the plot produced by the reservoir context menu item, **Plot Power**. Note that there is a new variable, **Power-Required**, which indicates how power was scheduled to meet energy requirements.
  19. Select the **Tabulate** from the plot **File** menu to see the tabulation.
  20. Select the **Release Decision** report to see when the power rule or other rules determined the powerhouse releases.
  21. From the simulation module **Reports** menu select the **Power Summary**.
  22. View and analyze the results using the power output options and other outputs such as the **Release Decision Report**.

### Questions

IX) What dates comprised the weekend in this simulation?

*The 21<sup>st</sup> and 22<sup>nd</sup> of June did not have a power requirement on the weekend. To verify the 21<sup>st</sup> and 22<sup>nd</sup> are Saturday and Sunday, edit the simulation and click the Lookback Date's "..." button to see a convenient calendar.*

X) Did the power plant generate power only on the required schedule? If not, what other rules cause power generation?

*No, the power plant also generated **secondary power** for the minimum conservation release rule and "GC" top of Conservation Zone storage limit.*

XI) What was the average power generated during the simulation?

*6.47 MW was the average power generated during the simulation, as indicated in the Power Summary Report.*

XII) What effect did the lower pool elevation at the beginning of the simulation period have on power generation?

*The power capability is lower due to the lower head. This resulted in less power generation than required by the schedule.*

XIII) Did the simulation make all releases through the power plant? If not, did these non-power releases occur during scheduled hydropower periods?

*The simulation released about half the total release through the Regulated Outlet during the periods when there was no scheduled power generation.*

➤ Part C – Outlet Allocation

**Problem Description**

In this part, you will add an outlet allocation to the reservoir to ensure all releases generate power. You will specify the appropriate allocation method and determine the effect on power generation during the simulation.

**Tasks** (continued from Part B)

23. In the **Simulation module** create a trial of the **Hydropower** alternative and name it **Outlet Allocation**.
24. Bring up the **Reservoir Editor** for Crazy Mountain reservoir
25. Select the **Operations** tab in Reservoir Editor
26. Select **Hydropower** Operation Set.
- **Section 1 - Adding outlet allocation to operation rule set**
  27. Select the **Rel. Alloc.** Tab.
    - At the dam level in the **Rel. Alloc.** dialog, select the **Sequential** allocation type.
    - Using the up-down arrow button move the **Power Plant** to the top of the list.
    - In this specification, all flow will pass through the power plant up to its capacity. If release beyond the power plant capacity is required, the Regulated Outlet will make the additional release. (*Note: you will need to create a new "allocation set" to be able to select sequential*).
  28. Close the reservoir editor and **Save** the **Simulation**.
  29. **Save** the Watershed.
- **Section 2 - Run the reservoir simulation trial**
  30. **Compute** the **Outlet Allocation** trial.
  31. Click **Close** on the **Compute** dialog when the simulation is complete.



- **Section 3 - Analyze the scheduled power simulation by examining the power output options**

32. Using the power output options and others as necessary, view and analyze the results...

**Questions**

XIV) Did the simulation make all releases through the power plant? Other than the specified flows in the lookback period, did the reservoir make any releases through other outlets?

*Yes, all releases passed through the power plant during the simulation. No other outlets made releases, except during the lookback period when there was a constant specified flow of 1,600 cfs through the regulated outlet.*

XV) Did the power plant generate additional incidental power?

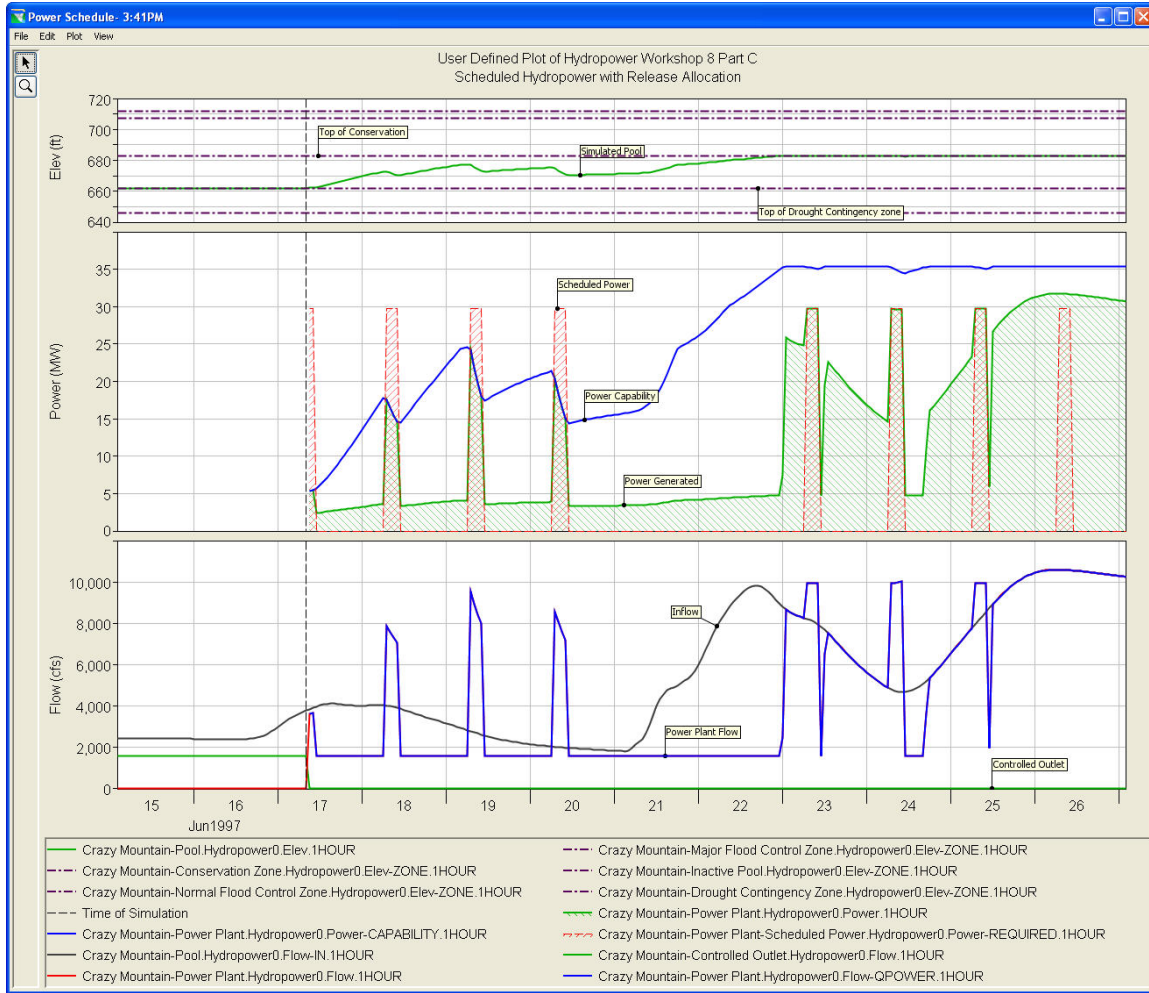
*Yes, during the unscheduled periods, the outlet allocation required all minimum flows and top of conservation storage limit flows to pass through the power house. This nearly doubled power flows during these periods.*

XVI) If the average plant factor from the Part C simulation applied to the whole month, how much energy would be generated? Is this the same as the monthly energy requirement? If not, why is it different?

*20,736 MWh (Average Plant Factor, 0.36 times 720 hours in June times installed capacity, 80MW) would be generated in June at this plant factor. Secondary power increased the plant factor during the simulation; by comparison, the June monthly requirement of 2500 MWh would compute to a plant factor of 0.04, presuming the required power schedule were met.*

XVII) Check both the alternative and the trial to compare generation. What was the increase in average power generated during the simulation when comparing the results of Part B and Part C?

*In Part B the average power generation was 6.47 MW. In part C with outlet allocation, the average power generation was 10.54 MW. This is an increase of 4.07 MW over the simulation period.*



User defined Plot of Part C simulation with outlet allocation applied.