Lab to Support ILO-6

Blended Near-Optimal Alternative Generation, Visualization, and Interaction for Water Resources Decision Making

Overview

State-of-the-art systems analysis techniques unanimously focus on efficiently finding optimal or pareto-optimal solutions. Yet water resources managers rather need decision aides that show multiple, promising, near-optimal alternatives. In this workshop, participants will use blended tools to generate, visualize, and interactively explore near-optimal alternatives to two optimization problems. The near-optimal alternatives perform within a tolerable deviation from the optimal stated objective function value of the original optimization problem. In Activity A, participants will explore near-optimal alternatives to the Phosphorus removal problem presented in (Rosenberg 2015) . In Activity B, participants will generate and explore near-optimal alternatives to a multi-objective reservoir management problem.

Learning Objectives

Upon successfully completing the workshop, participants will be able to:

- Formulate a near-optimal problem,
- Generate, visualize, and explore near-optimal alternatives to an optimization problem,
- Apply the near-optimal tools to a reservoir optimization problem,
- Help identify how the near-optimal tools can be improved.

Computer Requirements and Setup

Prior to the beginning of the workshop, participants must:

1. Install Matlab version 2013 or higher on your computer.
2. Install the General Algebraic Modeling System (GAMS) version 24.3.3 or more recent.
    a. Download from www.gams.com.
    b. In Matlab, add the directory where you installed GAMS to the Matlab Path. On the Ribbon, select **Home** tab=>**Environment**=>**Set Path**. In the Set Path window, click the **Add with subfolders…** button and navigate to the directory where you installed GAMS.
3. Download all code for the Blended Near-Optimal Tools from the GitHub repository at https://github.com/dzeke/Blended-Near-Optimal-Tools.
    a. Click the button labeled **Download ZIP** at the far right bottom.
    b. Unzip the folder
    c. Add the location where you unzipped the folder to the Matlab Path as in Step 2b.

Lab Activities

Below are the steps to follow to use the near-optimal tools in three directed activiteis. Instructions in **Bold** or *Italic* refer to Matlab or tool items (windows, menus, tabs, input items, etc.). *<u>Italicized, underlined sentences indicate questions that you should write the answer to before proceeding to the next step.</u>* If any point you have a question, consult the documentation materials (.txt files) that accompany each folder you downloaded in Step 3 or seek help from a facilitator.

If you have not already done so, install the required materials as directed above in Steps 1 to 4 (Computer Requirements and Setup).

<u>Activity #0. Verify the Installation</u>

4. Test use of the generation and visualization tools on a small 5-decision variable, linear optimization program. In Matlab, run the script LoadYourOwnModel.m. The script finds the optimal solution, generates 150 stratified-sampled alternatives from the feasible region of the problem, shows the vertices of the feasible region, and plots the results in parallel coordinates. More specifics of the problem are provided as comments in Lines 37-40 of the script file. At the Matlab command prompt, enter:

>> LoadYourOwnModel

You should see Figure 1. If yes, move on to Step 5, if not, seek help.

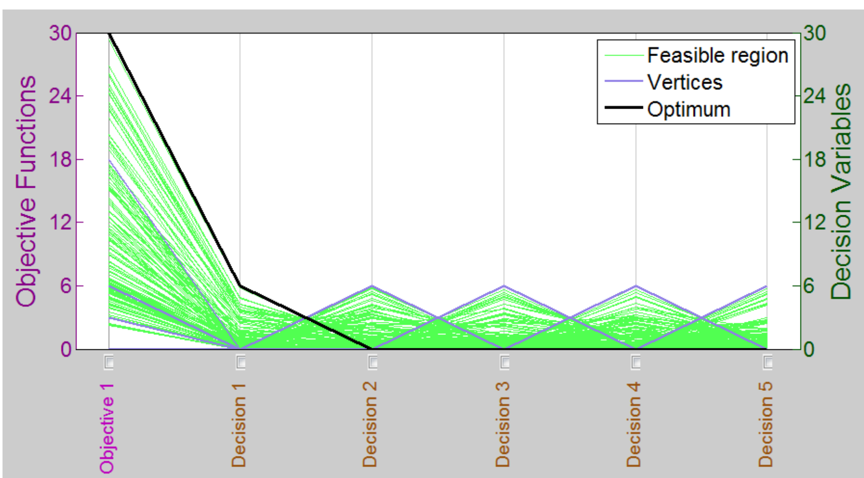

Figure 1. Output of LoadYourOwnModel.m

5. Test use of the generation and visualization tools on the much larger model for Echo Reservoir, Utah (Rosenberg 2015). In Matlab:

a. Change the Current Folder to \4-EchoReservoirApplication (or the folder where you unzipped the file WQNE_outG6.gdx in step 3b.

b. Enter the command:

   >> LoadEchoGamsResultsMGAComp('WQNE_outG6.gdx',3,2500,0,[0]);

c. This command will read the Echo Reservoir model data from GAMS including the optimal solution, stratify-sample 2,500 near-optimal alternatives whose objective function value is within 110% of the optimal removal cost, and plot the results in Parallel Coordinates. You should see Figure 2 below. (This figure is similar to Figure 3 in the manuscript except it omits purple lines representing alternatives generated by prior Modelling to Generate Alternatives (MGA) method).

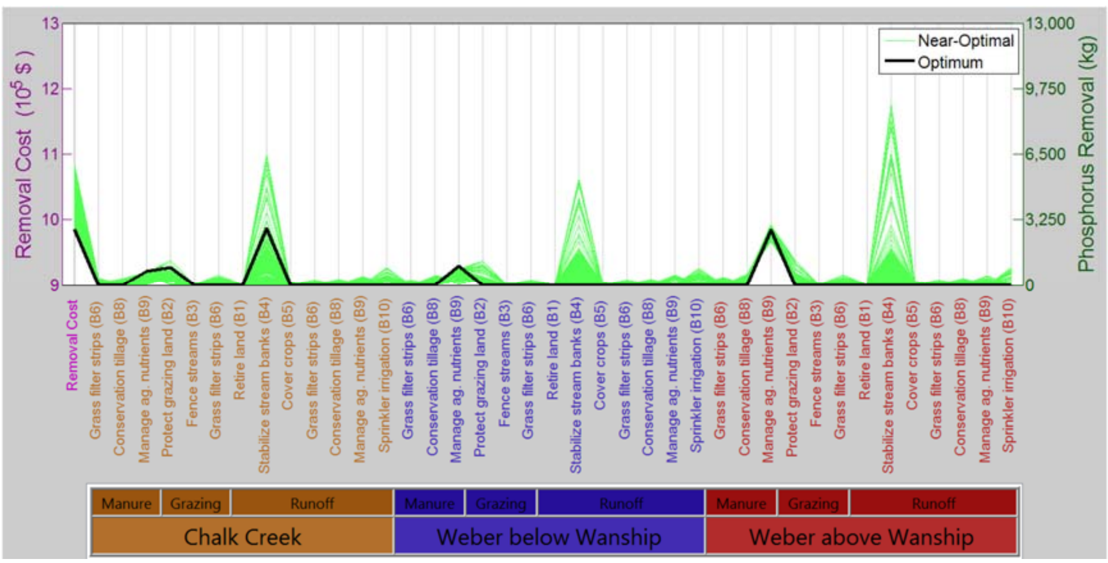

Figure 2. Optimal solution and near-optimal alternatives generated by the stratified sampling for the Echo Reservoir Phosphorus removal problem.

d. If you generated Figure 2, congratulations, you have successfully installed the blended near-optimal tools. If not, please seek help.

e. Look at Figure 2. *List three ways the near-optimal alternatives generated by the stratified sampling method differ from the optimal solution?*

Activity #B. Explore the Near-Optimal Region of the Phosphorus Removal Problem

6. *What near-optimal alternatives increase the phosphorus removed by stabilizing stream banks and shift implementation into the Weber below and above sub-watersheds?* To answer:

a. Use Matlab to open the file Fig_GenForNearOptPaper.m in the folder you created in Step 3.
b. Scroll down to Line 96 and begin following actions #2-10 listed as comments in the script (proceeded by %). Work from Figure 2 that you generated in Step 5d.
c. After finishing action #6 in the script (line 102), you should see Figure 3. <u>*What sliders change and what do these changes mean?*</u>

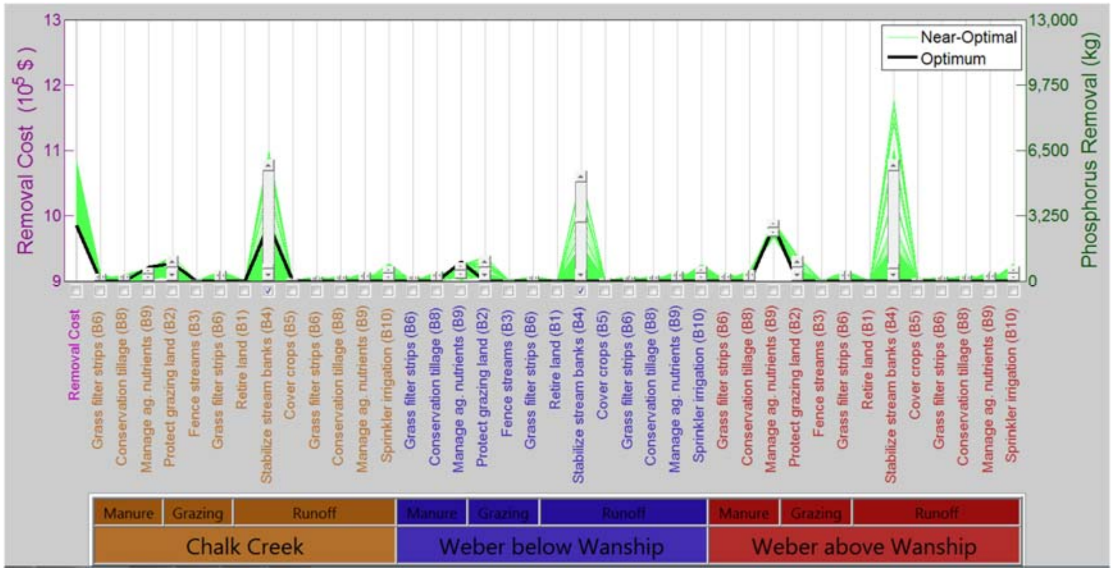

Figure 3. Near-optimal alternatives generated by shifting and increasing stream bank stabilization to the Weber below Wanship sub-watersheds.

d. Complete actions #7-10 in the script.
e. To highlight particular alternatives you generated
   i. On the **Display** tab in the **Group Traces** box, uncheck all the groups except for the 'Shifted stream bank' group you just created. Click the **Show Checked Groups** button.
   ii. On the **Controls** menu, select **Alternatives**=>**Show current**. The current alternative will highlight in green.
   iii. To select other alternatives, click the **Interact** tab. In the **Filter Existing Alternatives** box, use the arrows to scroll through the alternatives.

7. <u>*What is the effect on phosphorus removed when relaxing the near-optimal tolerance constraint (allowing a larger deviation from the optimal objective function value)?*</u>

   a. Using Figure 3 you generated in Step 6, follow the instructions on lines 276-300 in the file Fig_GenForNearOptPaper.m.

8. ***What near-optimal alternative for the Echo Reservoir problem did you select as preferred? Why?***

Activity #B. Generate Near-Optimal Alternatives for the Multi-Objective Reservoir Management Problem

9. Briefly review the reservoir management problem.

   The manager wants to maximize total (hydropower and irrigation) benefits by operating a reservoir subject to constraints on reservoir mass balance, reservoir capacity, hydropower turbine capacity, river mass balance, and maintaining an instream flow at a location downstream of the irrigation diversion. Hydropower turbine releases may be used for irrigation (Figure 4). Default input data for the problem is shown in Tables 1 and 2 (which the user can modify).

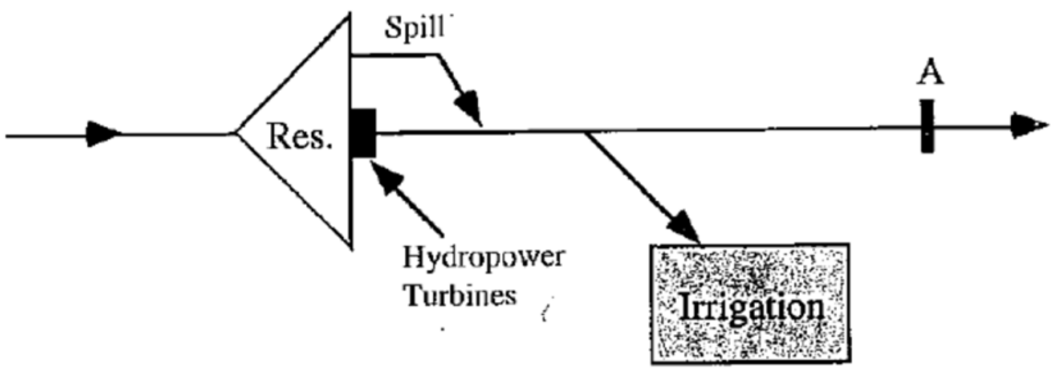

Figure 4. Schematic of multi-purpose reservoir operation problem

Table 1. Time series of default input data for reservoir problem

Time Step	Inflow (volume units)	Hydropower Benefits ($/volume)	Irrigation Benefits ($/volume)
1	2	1.6	1.0
2	2	1.7	1.2
3	3	1.8	1.9
4	4	1.9	2.0
5	3	2.0	2.2
6	2	2.0	2.2

Table 2. Additional default input data for reservoir problem

Parameter	**Value**
Initial reservoir storage (volume)	5
Maximum reservoir storage (volume)	10
Minimum required flow at A (volume/time)	1
Turbine capacity (volume/time)	4

The problem formulation is of the form:

Maximize cX

Subject to: (Aeq)X = (beq)

X >= lb and X <= ub

Where:

X is a vector that concatenates the principal decision variables of Storage, Spill, Hydropower Release, Irrigation Research, and Flow at A in each time step t. i.e., X = [Stor1, Stor2, … Stor6, Spill1 … Spill 6, Hydro1 … Hydro6, Irrigat1 … Irrigat6, FlowAtA1 … FlowAtA6],

c, lb, and ub are vectors of coefficients representing costs, lower bounds, and upper bounds that correspond to each decision variable in X.

Aeq and beq are a matrix and vector representing the coefficients of the equity constraints associated with reservoir and river mass balance constraints.

10. Generate the optimal solution

a. In Matlab, switch the path to the folder labeled *6-ReservoirOperation* that contains the file ReservoirOperationProblem.m

b. Enter the command:

```
>> ReservoirOperationProblem([])
```

The [] uses the default input data (see comments for directions to alter) and generates the optimal solution and plots the results in the parallel coordinate plotting tool. Ignore warnings in the command window that the polynomial is not unique.

c. *What is the optimal objective function value? How much water is spilled? Which use receives more water?*

11. Generate near-optimal alternatives.

a. Turn on the plot controls. From the **Controls** menu=>uncheck **Hide all controls**.

b. On the **Interact** Tab, enter a *Near Optimal* Tolerance value less than 1.

c. In the **Generate New Alternatives** box, enter the *# Samples*. This is number of alternatives to generate (e.g., a few hundred should suffice).

d. Click the **Generate** button. Matlab will calculate new alternatives and show them as purple lines in the plot.

e. Reformat the plot traces so it is easier to compare the near-optimal alternatives and optimal solution.

  i. Click the **Display** tab.

  ii. In the box labeled **Group Traces**, set the **Ord** for the row labeled **Optimum** to *2*. On the row labeled **Optimum_Resample**, set the **Ord** to *1*, **Name** to something meaningful like *Near-optimum*, and **Thick.** to *1*.

  iii. Click the button **Reorder Groups**.

f. *How do the near-optimal alternatives compare to the optimal solution?*

12. Additional options to explore the near optimal region to find preferred alternatives

a. View individual alternatives (**Control** menu=>**Alternatives**=>**Show current**. On the **Interact** tab in the **Filter Existing Alternatives** box, next to **Set to:** enter a number or use the arrows to scroll through the alternatives. The highlighted alternative will show in dark green.

b. Use sliders. (See step 6b.)

c. Relax the near-optimal tolerance constraint. (See Step 7).

d. Update the model formulation to include a new objective or constraint. (**Update Formulation**=>**Add new objectives**... and data entry in Figure 5 to enter a new objective to maximize hydropower generation benefits:

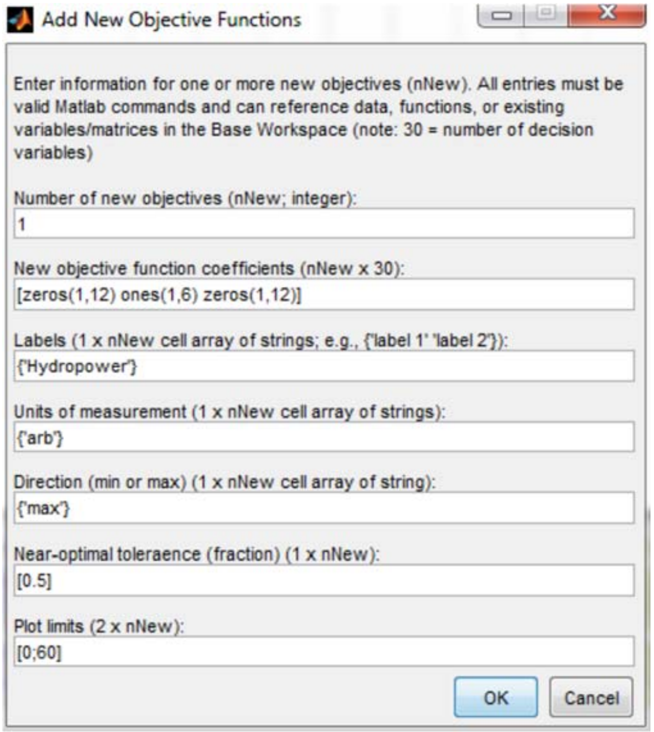

Figure 5. Updating the model formulation to add a new objective to maximize hydropower generation.

References

Rosenberg, D. E. (2015). "Blended near-optimal alternative generation, visualization, and interaction for water resources decision making." *Water Resources Research*, n/a-n/a. http://dx.doi.org/10.1002/2013WR014667.