Case Studies in Environmental and Water Resource Systems Based on Existing Literature and Texts

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INTRODUCTION

An attractive approach to the development of case studies for use in a course in environmental and water resource systems (EWRS) involves the use of existing journal articles and textbook chapters which contain enough information for a student to reproduce the study within the context of a typical semester project. Of the vast literature which summarizes case studies on EWRS, only a small fraction of that literature is suited for use as a case study in a course, because few studies provide enough information to reproduce the entire analysis. Often case studies reported in the literature are either too complex, omit important data, and/or do not provide a complete model formulation. In this chapter, a selected group of case studies which I have used successfully in my course CEE-214 Environmental and Water Resource Systems¹ at Tufts University are described. The motivation here is that the process of reproducing an application from a published journal article or textbook chapter assures the following:

- 1. The student must become fully acquainted with every detail of the case study in order to implement, understand, summarize and present the model results.
- 2. The level of confidence associated with the students' knowledge regarding EWRS tends to increase considerably when they realize that they can reproduce the results of a peer reviewed journal article.
- 3. Each case study can be implemented with only an introductory level background in systems analysis. The project is designed to be completed near the end of a semester, taking a student about 2-3 weeks to complete and culminating in both a project report and an oral presentation.
- 4. If an entire class in EWRS participates in a case study, with each student selecting a different case study, then each student takes complete ownership of their work.
- 5. Normally these projects are completed by individual students so that each student takes full ownership of a study. It is possible for several students to work on the same case study, as long as each student generates their own project report and oral presentation.

¹ This is a required course for all graduate students in the environmental and water resources engineering program in the department of civil and environmental engineering at Tufts.

- From: Vogel, R.M., Case Studies in Environmental and Water Resource Systems Using Journal Articles and Textbooks, Chapter 10 in: Watkins, Jr., D.W., editor. (2011). Case Studies in Environmental and Water Resources Systems Analysis: Data and Models for Decision Making, American Society of Civil Engineers, Reston, VA., 2011.
 - 6. The oral presentations which result from the wide range of different studies presented in this chapter, as well as other chapters in this text, will enrich and educate the entire class regarding the wide applicability of EWRS analysis.

The case studies summarized in this chapter have the following common characteristics:

- 1. Each case study is completely self-contained, so that the cited article or book chapter contains examples which can readily be reproduced by a student in a first course in systems analysis.
- 2. Most of the case studies described here are formulated as linear programs or mixed integer linear programs; though several are nonlinear programs.
- 3. Each case study includes all the relevant data needed as well as a full description of the model formulation.
- 4. The case studies are relatively small problems, usually consisting of fewer than 100 decision variables, so that free software such as the student versions of LINDO and LINGO (LINDO Systems, http://www.lindo.com/) can be used to implement the case study.

Guidance to Students Regarding Case Studies and Presentations

Each student must select and solve an environmental/water resource systems engineering, planning or management problem which interests them. After choosing a suitable case study, each student is expected to formulate and resolve the problem presented in the article. The student is not required to duplicate everything done by the authors; *you are only required to implement an example which generally reflects what the authors have done.* If for some reason the authors have not given you adequate information to duplicate their own analysis, you are allowed to assume default values for any variables you wish.

In addition to a project report (approximately 5-8 pages, single spaced), each student should deliver a 10-12 minute oral presentation summarizing the overall project, followed by 3-4 minutes of questions and discussion. Your oral presentation should include the following: introduction and background to problem; optimization problem formulation, with description of objectives and constraints in words (and if appropriate, mathematical terms as well); and a summary of interesting results and conclusions.

Oral presentations are expected to mimic the types of oral presentations given at the American Geophysical Union meetings and other conferences, where presenters have only 10-12 minutes to introduce a complex problem and provide general results. For guidelines on giving a short technical presentation, go to <u>www.agu.org</u> and search on "presentations". You will find many guidelines which are easily downloaded.

If you have any questions about the appropriate content of your presentation, you should discuss your presentation with the instructor on an individual basis, prior to your

oral presentation. If you run into any problems with your analyses prior to your oral presentation, such as obtaining results that are significantly different from the original author's results, you should be sure to consult the instructor prior to your oral presentation.

EXAMPLE CASE STUDIES

Case Studies from Journal Articles:

The primary methods used to formulate and solve the following problems include the use of linear programming (LP), nonlinear programming (NLP) and mixed integer linear programming (MILP). The primary method associated with each case study is identified using these qualifiers.

Optimal Water Allocation (LP)

Journal Article:

- An Optimization Approach for Multi-Sectoral Water Supply Management in the Greater Beirut Area, by Yamout, G. and El-Fadel, *Water Resources Management*, Volume 19, No. 6, pp 791-812.
- **Summary:** This paper presents a linear programming model that was developed and applied to serve as a water supply multi-sectoral decision support system for water resources management taking economic and socioenvironmental factors into consideration. The applicability of the model was tested in the Greater Beirut Area by examining future supply-demand management alternatives and quantifying the costs and benefits of viable policies. The effect of eliminating a particular source to account for resources depletion and public acceptability, as well as increased returns from water use, are shown to have a very large impact on the resulting water allocation scheme. The optimization model is also shown to be a useful tool to assess the effect of decreasing unit costs from water supply options (desalination) and the resulting breakeven point, and the effect of increased water demand due to unplanned growth (tourism).

Optimal Site Level Stormwater Management (LP)

Journal Article:

Geographic Information Systems, Decision Support Systems and Urban Stormwater Management, by Sample, D.J., J.P. Heaney, L.T. Wright and R. Koustas, *Journal of Water Resources Planning and Management*, Volume 127, No. 3, 155-161, 2001.

- From: Vogel, R.M., Case Studies in Environmental and Water Resource Systems Using Journal Articles and Textbooks, Chapter 10 in: Watkins, Jr., D.W., editor. (2011). Case Studies in Environmental and Water Resources Systems Analysis: Data and Models for Decision Making, American Society of Civil Engineers, Reston, VA., 2011.
 - **Summary:** This article introduces a very simple linear programming model for determining the optimal configuration of a neighborhood scale lot with the goal of minimizing runoff volumes. The neighborhood scale application includes a GIS, a database, a storm-water system design template, and an optimization capability for screening alternatives. The land-use and soil-type based Soil Conservation Service (SCS) method is used for calculating runoff from GIS information. Using economic analysis to compare the cost of controls, including the opportunity cost of land for land intensive controls, the optimal mix of best management practice (BMP) controls was found using linear programming. Finally, a single site example is presented illustrating the value of GIS tools to provide more complex on-site hydrologic analysis. This example is simpler and shorter than many of the other case studies reported here. Thus the student would be expected to provide a critical analysis of the formulation and model results in addition to possible extensions and improvements.

Optimal Design of Small Reservoirs or Ponds for Water Supply – Appropriate Technology (NLP)

Journal Article:

- Optimal Design of Small Reservoir Systems, by Sharma and Helweg, *Journal of the Irrigation and Drainage Division* ASCE, 108(4), 250-264, 1982.
 (Also see Helweg and Sharma, *Water Resources Research*, 19(4), 881-885.)
- **Summary:** Small reservoirs or ponds, often called tanks in underdeveloped countries, are an important component of traditional water harvesting methods in the semi-arid tropics of India and elsewhere. Though considerable investment is often involved in such tanks, few studies have explored the optimal or efficient design of such tanks. These two papers introduce a nonlinear optimization approach to design of the tanks. The approach shown here is 'appropriate technology' because a traditional approach is combined with newer techniques to improve irrigation systems without capital-intensive technology construction methods. Previous students who have implemented this model formulation have found that it is possible to obtain significant improvements in the solutions reported by the authors of these two studies using modern search methods such as genetic algorithms. Students will need to read both studies to obtain sufficient information to formulate the problem.

Optimal Design of Water Distribution Systems (NLP)

Journal Article:

- Optimal Design Method of Looped Water Distribution Network, by Bai, D. Yang P, and Song, L., *Systems Engineering – Theory and Practice*, Vol. 27, No. 7, pp. 137-143, 2007.
- **Summary:** A new procedure is presented to optimize a looped water distribution network using a linear programming algorithm. Here the objective is to minimize annual cost (or investment). Although there are some complex discussions of quadric orthogonal circumrotation regression, the student can ignore these and focus entirely on the LP formulation and application. The optimal design of the looped network is determined by linear programming based on the optimal flow distribution scheme. The procedure can be used to optimize the single resource looped network with a pump station.

Groundwater Management (MILP)

Journal Article:

- Economic Development of Groundwater in Arid Zones with Applications to the Negev Desert, Israel, by Brimberg, J., A. Mehrez and G. Oron, *Management Science*, Vol. 40, No. 3, pp. 353-363, 1994. (Also see their article "A model for the development of marginal water sources in arid zones: the case of the Negev Desert, Israel, *Water Resources Research*, 29(9), 3059-3067, 1993)
- **Summary:** A mixed integer linear program is formulated to determine the economic development of marginal groundwater sources at local demand sites in an arid region. These marginal sources are required to augment the supply from an over-drafted regional source. The model accounts for variable costs of supply, fixed investment costs, capacity constraints at the regional and local levels, and water quality requirements at the local sites. The more advanced analytical approaches described in sections 3 and 4 should be ignored and omitted from the project.

Optimization of Groundwater Resources (LP and MILP)

Journal Article:

Optimization models in groundwater management, based on linear and mixed integer programming: An application to a Greek Hydrogeological Basin, by Psilovikos, A.A., *Phys. Chem. Earth, B.*, 24(1-2) 139-144, 1999.

> **Summary:** The paper compares two optimization methods used in groundwater management, based on linear as well as on mixed integer programming (LP and MILP). The solution, obtained by use of combined simulation - optimization models, consists of three steps (Psilovikos, 1996): (1) Simulation model - MODFLOW, (2) Management (response coefficient) model - MODMAN, and (3). Optimization model - LINDO. A hydrogeological basin in Northern Greece was used as a case study in this project. The collected data are based on 26 managed wells for a period of 12 months (Psilovikos et al, 1996), but to reduce the amount of calculations, only 4 managed wells were selected for a period of 3 months. The results obtained from the solution with the two methods (LP and MILP) show a) both models satisfy the same piezometric and balance constraints; and b) the MILP model is more complicated and the feasible region of solutions is more constrained than the LP model, because a number of integer constraints are added (i.e., the LP model can be considered as the relaxed version of the MILP). Students have found that if one makes reasonable assumptions about the response coefficients, which are not given, credible and reasonable results can be obtained.

Groundwater Aquifer Management (LP)

Journal Article:

- Ground-Water Hydraulics in Aquifer Management, by E. Aguado and I. Remson, *Journal of the Hydraulics Division*, *ASCE*, Vol. 100, No. HY1, 1974.
- **Summary:** This paper describes how the physics of an aquifer can be used to develop a groundwater management model. An LP management model of a groundwater aquifer system is formulated to include the groundwater state variables as decision variables in the optimization model. Finite-difference approximations of the governing differential equations then become simply constraints in the LP model. Several case studies are provided as examples. Cases include a confined and an unconfined aquifer, a one- and two-dimensional problem, and a steady-state and transient case. These examples illustrate the feasibility and inherent problems associated with the approach. The student may elect to solve only two or three of the examples given in the paper.

Optimal Dam Removal Strategies (MILP)

Journal Article:

- From: Vogel, R.M., Case Studies in Environmental and Water Resource Systems Using Journal Articles and Textbooks, Chapter 10 in: Watkins, Jr., D.W., editor. (2011). Case Studies in Environmental and Water Resources Systems Analysis: Data and Models for Decision Making, American Society of Civil Engineers, Reston, VA., 2011.
 - Optimizing the removal of small fish passage barriers, by J.R. O'Hanley, and D. Tomberlin, *Environmental Modeling and Assessment*, Vol. 10, pp. 85-98, 2005.
 - **Summary:** Removal of small barriers such as dams that hinder the upstream migration of fish is a major challenge in riparian habitat restoration. Due to budget limitations, it is necessary to prioritize barrier removal and repair decisions. These have usually been based on scoring and ranking procedures, which, although simple to use, can be very inefficient in terms of increasing the amount of accessible instream habitat. The paper describes a decision model based on a mixed integer linear program (see Figure 3 example) which leads to optimal repair and removal decisions. Results indicate that using an MILP can lead to much more efficient decisions than those based on traditional scoring methods.

Optimal Water Reuse (LP)

Journal Article:

- A Case Study of Water Reuse in an Industrial Park, by Keckler, S.E. and D.T. Allen, *Journal of Industrial Ecology*, Vol. 2, No. 4, 1999.
- **Summary:** The techniques of water distribution modeling, a well-developed subject, have been applied to water management in an industrial park--the Bayport chemical manufacturing complex in Houston, Texas in the United States. Linear programming and other mathematical programming approaches were used to evaluate water reuse opportunities for a variety of scenarios, including redesigning the industrial water use network, adding a facility to the network, limiting the total water available to the network, and varying the price of water. The results of the modeling demonstrate that a number of economical water reuse opportunities may exist for this network of facilities. More generally, the types of mathematical models developed for water reuse may find application in reuse modeling for other materials.

Optimal Design of Levees (NLP)

Journal Article

Up or Out? – Economic-Engineering Theory of Flood Levee Height and Setback, by T. Zhu and J.R. Lund, *Journal of Water Resources Planning and Management*, Vol. 135, No. 2, pp. 90-95, 2009.

Summary: Levee setback, location, and height are important issues in flood levee system design and modification. This paper derives an economic-engineering theory of the optimal trade-off of levee setback for

height both for original and redesigned flood levees, demonstrating the interconnection of levee setback, height, costs and risks, and economically optimal design. These analyses assume stationary flood hydrology and static ratios among damageable property value, unit construction cost, and land price. The economic trade-off of levee setback for height depends on economic cost and benefit and hydraulic parameters, and only indirectly on flood frequency and economic damage parameters. The redesign rules derived in this paper indicate conditions where existing levees should be raised or moved in response to changes in conditions. Numerical examples illustrate the results. This paper demonstrates several ideas and theory for economic flood levee system planning and policy rather than providing guidelines for direct design practice.

Reservoir Management and Design (LP)

Journal Article

The Linear Decision Rule in Reservoir Management and Design 1: Development of the Stochastic Model, by Revelle, C., E. Joeres and W. Kirby, *Water Resources Research*, Vol. 5, No. 4, Water Resources Research, 1969.

Abstract With the aid of a linear decision rule, reservoir management and design problems often can be formulated as easily solved linear programming problems. The linear decision rule specifies the release during any period of reservoir operation as the difference between the storage at the beginning of the period and a decision parameter for the period. The decision parameters for the entire study horizon are determined by solving the linear programming problem. Problems may be formulated in either the deterministic or the stochastic environment. This is one of the most famous papers on LP in our field.

Good Case Studies from Textbooks and other Books:

The following project ideas are basically short examples created in textbooks on environmental and water resource systems analysis, which contain the problem statement, problem formulation, along with associated figures, tables and all data necessary to reproduce the example problem. They are ideal examples of projects in a course because they provide all the relevant information needed, along with detailed explanations of the model formulation.

- 1. **Irrigation planning**, Chapter 8, pp.392-416 in *Water Resource Systems Planning and Analysis*, by D.P. Loucks, J.R. Stedinger and D.A. Haith, Prentice Hall, 1981.
- 2. **Regional wastewater treatment and transport**, Chapter 10, pp.515-519 in *Water Resource Systems Planning and Analysis*, by Loucks, Stedinger and Haith, Prentice Hall, 1981. (Also see "Siting regional environmental

facilities" in Chapter 14 of the text by Revelle and McGarity, 1997, described below.)

- 3. **Regional water supply and wastewater disposal**, pp. 418-423 in *A Systems Approach to Civil Engineering Planning and Design*, by T.K Jewel, Harper and Row, 1986.
- 4. **Reservoir operations for water supply**, pp. 203-215, in *Systems Approach to Water Management*, by A. Biswas, McGraw Hill Book Co., 1976.
- 5. **Optimal river water quality management**, Chapter 2, pp. 70-83, in *Design and Operation of Civil and Environmental Engineering Systems*, by Revelle and McGarity, Wiley, 1997. (There are actually a few examples given in this chapter, along with all the data given in the appendix for each example).
- 6. **Management of agricultural nonpoint source pollution**, Chapter 6 in *"Environmental Systems Optimization"* by D.A. Haith, Wiley, 1982. (This example is extremely rich and might be good for two people to work on, where the two students would help each other formulate the basic problem and each would then focus on different but related problems. In this case, exercise 6-1 on page 157 of their text describes an extension of the problem to examine soil and water conservation practices.)
- 7. **Planning of municipal wastewater treatment**, Chapter 3 in "*Environmental Systems Optimization*" by D.A. Haith, Wiley, 1982.
- 8. **Multiobjective land management planning,** Chapter 7, pp.173-179, in *"Environmental Systems Optimization"* by D.A. Haith, Wiley, 1982.
- 9. **Reservoir design**, Chapter 7, pp. 333-339, in *Water Resource Systems Planning and Analysis*, by Loucks, Stedinger and Haith, Prentice Hall, 1981.