INTEGRATED APPROACHES TO THE OPTIMAL DESIGN OF MULTISCALE SYSTEMS

A Dissertation

by

EVA M. LOVELADY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2008

Major Subject: Chemical Engineering

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Approved by:

Chair of Committee,	Mahmoud M. El-Halwagi
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ABSTRACT

Integrated Approaches to the Optimal Design of Multiscale Systems.

(August 2008)

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Chair of Advisory Committee: Dr. Mahmoud M. El-Halwagi

This work is aimed at development of systematic approaches to the design of multiscale systems. Specifically four problems are addressed: environmental impact assessment (EIA) of new and retrofitted industrial processes, integration of process effluents with the macroscopic environmental systems, eco-industrial parks (EIP), and advanced life support (ALS) systems for planetary habitation. While design metrics and specific natures of each problem poses different challenges, there are common themes in the devised solution strategies:

a. An integrated approach provides insights unseen by addressing the individual components of the system and, therefore, better understanding and superior results.
b. Instead of dealing with multiple scales simultaneously, the design problem is addressed through interconnected stages without infringing upon the optimization degrees of freedom in each stage. This is possible through the concept of targeting.
c. Mathematical programming techniques can be used effectively to systematize the integration concepts, the target identification, and the design of multi-scale systems.

The dissertation also introduces the following specific contributions:

i. For EIA, a new procedure is developed to overcome the limitations of conventional approaches. The introduced procedure is based on three concepts: process synthesis for systematic generation of alternatives and targeting for benchmarking environmental impact ahead of detailed design, integration of alternative with rest of the process, and reverse problem formulation for targeting.

ii. For integrating process effluents with macroscopic environmental systems, focus is given to the impact of wastewater discharges on macroscopic watersheds and drainage systems. A reverse problem formulation is introduced to determine maximum allowable process discharges that will meet overall environmental requirements of the watershed.

iii. For EIPs, a new design procedure is developed to allow multiple processes to share a common environmental infrastructure, exchange materials, and jointly utilize interception systems that treat waste materials and byproducts. A source-interception-sink representation is developed and modeled through an optimization formulation. Optimal interactions among the various processes and shared infrastructure to be installed are identified.

iv. A computational metric is introduced to compare various alternatives in ALS and planetary habitation systems. A selection criterion identifies the alternative which contributes to the maximum reduction of the total ESM of the system.

DEDICATION

I would like to dedicate this work to my parents, James and Julia Lovelady, my siblings Beverly, Jimmy and Sandra, my friend Jonathan Chadwick, my sister-in-law Jennifer and my nephews Justin and John. Though it has always been my desire to pursue my Ph.D., it was through their never ending encouragement, support and inspiration that I was able to make the decision to return to academia. Throughout the course of my graduate studies, they have provided the light, strength and, from time to time, the reality checks which helped me to maintain focus to pursue my dreams and achieve success.

ACKNOWLEDGMENTS

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My deepest appreciation goes to my dissertation committee members, Dr. Sergiy Butenko, Dr. Juergen Hahn, Dr. M. Sam Mannan, for their service on my dissertation and for their invaluable insight and support.

I have also had the pleasure of collaborating with numerous colleagues outside of Texas A&M University. I wish to thank Dr. Heshmet Aglan and Jill Hill at Tuskeegee University for the collaboration on the ALS work. I would like to thank Dr. Amro El-Baz, Dr. Kamal Ewida and Dr. Diaa El-Monayeri at Zagazig University, Egypt for the collaboration on the Bahr El-Baqar Watershed work. Lastly, I would like to thank Chris Ball, with Tetra Point Fuels, for the collaboration of an ongoing project regarding biofuels.

I wish to thank all of the members of my group for their constant support and cooperation, particularly Vasiliki Kazantzi, Daniel Grooms and Grace Nworie.

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CHAPTER I

INTRODUCTION

The focus and scale of designing chemical engineering systems have gone through a constant evolution. Early chemical engineering application focused on the unit as the key building block of any process. This has led to the concept of unit operations which was instrumental in understanding and designing numerous units such as reactors, separation devices, pumps, compressors, turbines, etc. Next, focus was given to the basic underlying phenomena that govern the performance of the units. As such, transport phenomena evolved as a framework for explaining microscopic phenomena in a consistent manner and relating these phenomena to the performance of individual units. Next came process integration, which is a holistic approach to the design and operation of the process with a hallmark of emphasizing the unity of the process. This approach recognizes that there are "big picture" insights that cannot be seen be designing individual units and that these individual units must be interconnected in an integrated way that is geared towards the optimal performance of the whole system and not necessarily individual units. At present, with growing focus on macroscopic systems (e.g., sustainability, global climatic changes, regional pollution problems, and watersheds), there is a need to develop design procedures that link the performance of individual streams, units, and processes with the broader environmental system. This is the key motivation for this dissertation. The overall objective of this work is to develop systematic and generally applicable design procedures that can effectively and efficiently address multiscale systems. Specifically four

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This dissertation follows the style of *Computers and Chemical Engineering.*

problems are addressed: (1) environmental impact assessment of new and retrofitted industrial processes, (2) integration of process effluents with the macroscopic environmental systems, (3) eco-industrial parks, and (4) advanced life support systems for planetary habitation.

A consistent approach is adopted for addressing these four problems. The approach has common features of (1) using systems integration as an overarching approach to analyzing and designing the systems, (2) developing targeting techniques to benchmark performance of certain scales and enable the solution of the multiscale problem as a set of interconnected stages, each of which is handled at the proper scale, and (3) using mathematical programming as a powerful tool for systematizing design decisions.

Instead of providing a common literature survey chapter and a common problem statement, the dissertation is organized in separate chapters, each addressing one of the four targeted problems. Consequently, each chapter will have its own literature search and problem statement along with the devised design procedure and case study. Chapter II addresses the problem of environmental impact assessment and introduces a procedure for including design decisions and insights early enough in the assessment. Chapter III presents a reverse problem formulation for integrating process effluents with macroscopic environmental systems. Chapter IV describes a methodical way of designing eco-industrial parks that enable material exchange and common treatment infrastructure for multiple processes. Chapter V addresses the problem of designing integrated systems used in planetary habitation and advanced life support systems. Finally Chapter VI presents the overall conclusions of this dissertation and recommendations for future work.

CHAPTER II

PROCESS INTEGRATION AS AN ENABLING TOOL IN ENVIRONMENTAL IMPACT ASSESSMENT

II.1. INTRODUCTION

Environmental impact assessment (EIA) is a procedure for determining, assessing, and mitigating the biological, physical, chemical, economic, and social consequences of a proposed project of the environment. It is a very useful activity that is aimed at proper accounting for the environmental effects of a project and preventing the adverse impacts of the project before authorization is given and major commitments are made (Noble, 2005; Morris & Thérivel, 2001; Marriott, 1997). EIA has an important effect on the selection of design alternatives. Once potential environmental problems are identified, the design is altered or a new design alternative is generated to address the concerns raised during the analysis. When the focus is the analysis of policies, plans and programs for an area, a region or a sector, the broader notion of strategic assessment (SEA) is invoked (Dalal-Clayton & Sadler, 2005; Thérivel & Partidário,1996).

Cognizant of the need for EIAs', countries around the world have enacted regulations for the nature, scope, and format of EIAs. While the specific implementation procedures may differ from one country to another, there are common themes for a conventional EIA and for its documentation (referred to as the environmental impact statement "EIS"). Typically, an EIA involves a variation of the following steps:

1. **Project Description:** This is an overview of the nature and objectives of the proposed project. The description should also discuss the main features of the production process, the selected site, and a basic characterization of the interactions with environmental and social components.

2. **Screening:** This refers to the determination of which projects or parts of a project require an EIA

3. **Scoping:** which involves a top-level analysis for the identification of the primary matters to be included in the EIA and the extent to which these matters should be addressed.

4. **Description of the Baseline Environment :** In order to track any consequences of the proposed project on the environment, it is important to report information and data (e.g., physical, biological, economic, social) for the existing environment. This activity should also describe interacting components of the environment (e.g., industry, residential, etc.), and planned developments.

5. **Generation of Alternatives and Process Description:** This step involves the generation and characterization of the candidate technologies and solutions for the project. For each alternative, a process description is developed to give sufficient details on the process (e.g., block flow diagrams, basic mass and energy balances, needed labor, construction phases, site information, etc.). Assumptions, design bases, and data gaps/uncertainties should be documented.

6. **Impact Identification:** which aims to provide a top-level (usually qualitative) analysis of the impacts of project activities with emphasis on which ones warrant a detailed study.

7. **Impact Prediction and Evaluation:** This step involves the (quantitative whenever possible) assessment of the consequences of the planned activities on the environment. Both positive and negative impacts are described in terms of their magnitude, significance,

reversibility, frequency of occurrence, period of occurrence and nature of the impact. There are several methods used in predicting and evaluating the impacts. Examples include check-lists, matrix methods, and mathematical models. Check-list methods involve the use of forms and guiding questions. Matrix methods provide a two-dimensional approach for assessing the type and extent of environmental impacts. An example is the Leopold matrix which lists the project activities (e.g., raw materials consumption, processing units, water supply, energy supply, construction work, atmospheric emissions, liquid effluents, solid wastes) versus the physical, biological, and social conditions of the environment (e.g., air, water, soil, fauna, flora, population, economy). Whenever, there is a significant interaction between a column and a row, a diagonal line is drawn across the corresponding cell. Then, two numbers (on a scale of 1-10) are entered above and below the line, respectively designating magnitude and importance of the interaction. Finally, mathematical-modeling approaches provide a quantitative method for evaluating the spatial and temporal impacts of the targeted environmental phenomena. They may be mechanistic, semi-empirical, and empirical models. Examples include air-dispersion and water-quality models (Turner, 1994; Arya, 1999; Martin & McCutcheon, 1998; El-Baz, et.al. ,2005a).

8. Impact Mitigation: Based on impact prediction and evaluation, the magnitude and importance of consequences to the environment are determined. For all the negative repercussions, the company must evolve mitigating measures to eliminate or abate (to an acceptable level) the environmental impact. Several approaches are adopted including design and operating modifications of the project, addition of waste treatment systems, and consideration of additional alternatives. In addition to assessing the environmental impact of the mitigating solutions, their techno-economic performance must also be assessed to insure feasible and realistic implementation. If no viable solution is found, the proposed project is stopped. Therefore, it is necessary to include effective and efficient process engineering methods at this stage.

9. Environmental Monitoring Plan: In order to sustain an environmentally-acceptable operation, a monitoring document must be developed to describe the monitoring plan and the roles of involved personnel.

10. Documentation and Review of the EIS: To document the EIA process, discussions, findings, and recommendation, the EIS is prepared. It should include an overview of the EIA procedure, project and process descriptions, baseline characterization of the environment, a list of the considered alternatives, the technical, economic, and environmental performance and impact of the alternatives, the recommended options, and comments on the path forward. Once the EIS document is completed, it is reviewed by the decision makers (e.g., environmental agency) for final comments and approval. The decision makers may approve, select one of the project alternatives, require modifications, send back for additional studies, or reject the proposed alternatives. It is worth noting that interactions between the developer (company) and the decision makers should be active throughout the foregoing steps. This is needed to factor proper feedback and insure appropriate progress. Additionally, public participation is usually solicited before final approval. Finally, post-EIA audits are usually required to verify progress as planned once implementation is started. A schematic representation of the key steps in a typical EIA procedure is shown in Fig. 2.1.

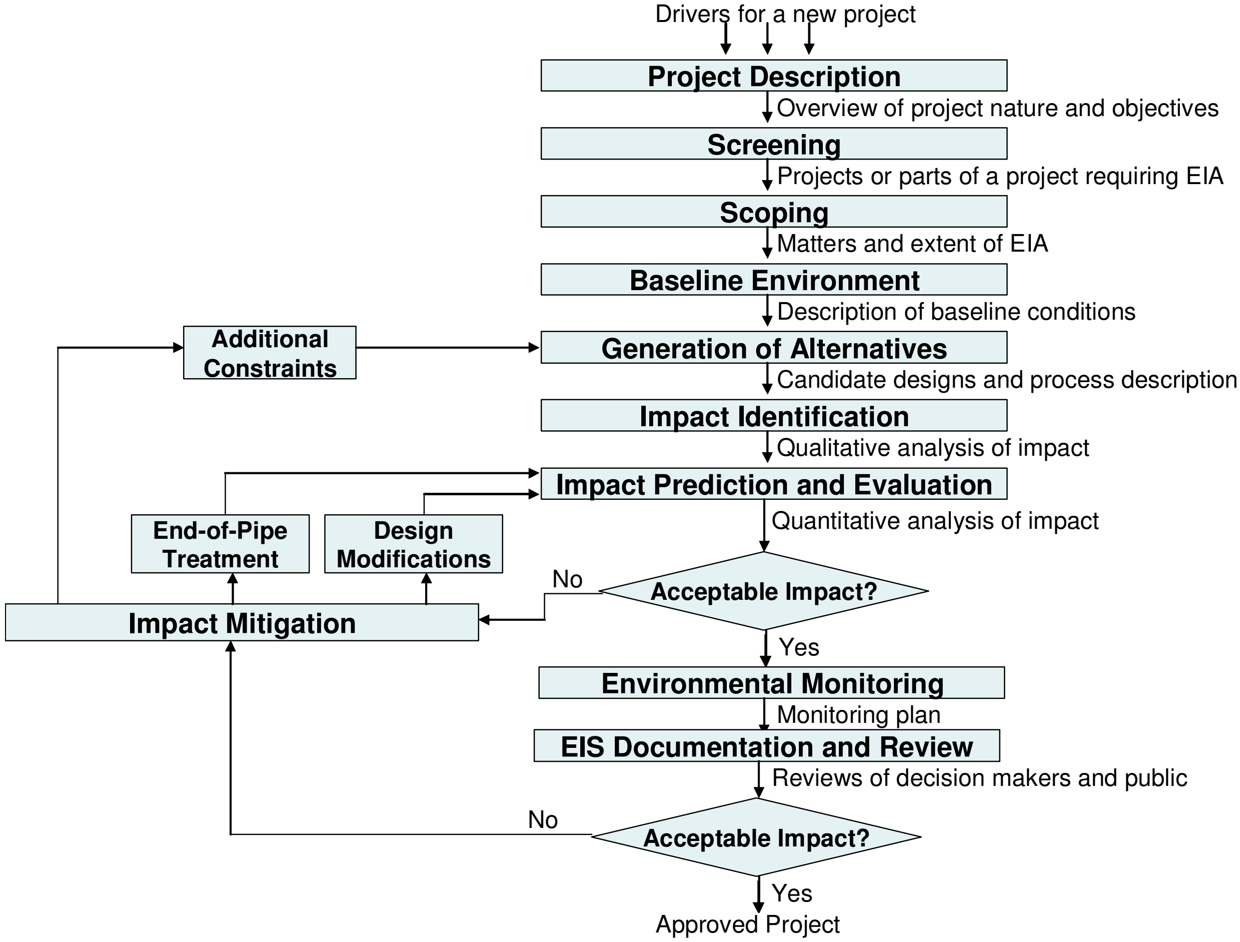

Fig. 2.1. Steps in a Typical EIA Procedure

II.2. PROCESS ENGINEERING LIMITATIONS OF TYPICAL EIAs

It is instructive to view the EIA procedure from the perspective of process engineering activities. This is shown in Fig. 2.2. For a given project, various design alternatives are first proposed. The generation of these design alternatives is normally carried out based on brainstorming, evolutionary techniques, and heuristics. Given the numerous potential design alternatives, such approaches are not guaranteed to provide an optimum or near-optimum solution except in simple cases. They are also not guaranteed to generate a rich-enough set of alternatives. For each generated alternative, the process engineering team must perform a techno-economic analysis (e.g., simulation, conceptual design, cost estimation, profitability, etc.) and safety assessment (e.g., hazard and operability analysis "HAZOP" or hazard identification "HAZID"). Then, it is necessary to perform environmental-impact identification, prediction, and evaluation for each alternative. If the evaluated impact is unacceptable, then mitigation techniques are invoked. These typically include design modifications, end-of-pipe treatment, and incorporation of emerging constraints and generation of new alternatives. If the impact is acceptable, then the EIS is prepared, discussed with decision makers and with the public. As a result, the alternative may be accepted, altered, or rejected. The accepted alternatives then become ready of implementation.

The aforementioned steps have several limitations from a process-engineering viewpoint. First, a large number of alternatives may have to be generated. For each alternative, techno-economic and safety analyses are performed. While explicit environmental regulations are typically included as constraints in generating alternatives, the more compounded environmental effects are not. For example, while an alternative may satisfy certain emission limits, the process discharges may interact with other environmental phenomena and neighboring systems that render the overall impact unacceptable. Since these compounded impacts are detected during the impact identification, prediction, and evaluation phase of the EIA, it is possible to reject many alternatives during that phase. This is frustrating for the process engineers since much effort have gone into the generation and analysis of the alternatives. Also, the mitigation measures may not be easily generated and are likely to be generated through brainstorming and heuristics.

To overcome these limitations, process integration is proposed an effective framework in facilitating process-engineering activities associated with the EIA, reducing the engineering efforts, gaining valuable insights early enough in the process, and systematizing the design effort while reconciling the various process objectives with the environmental objectives.

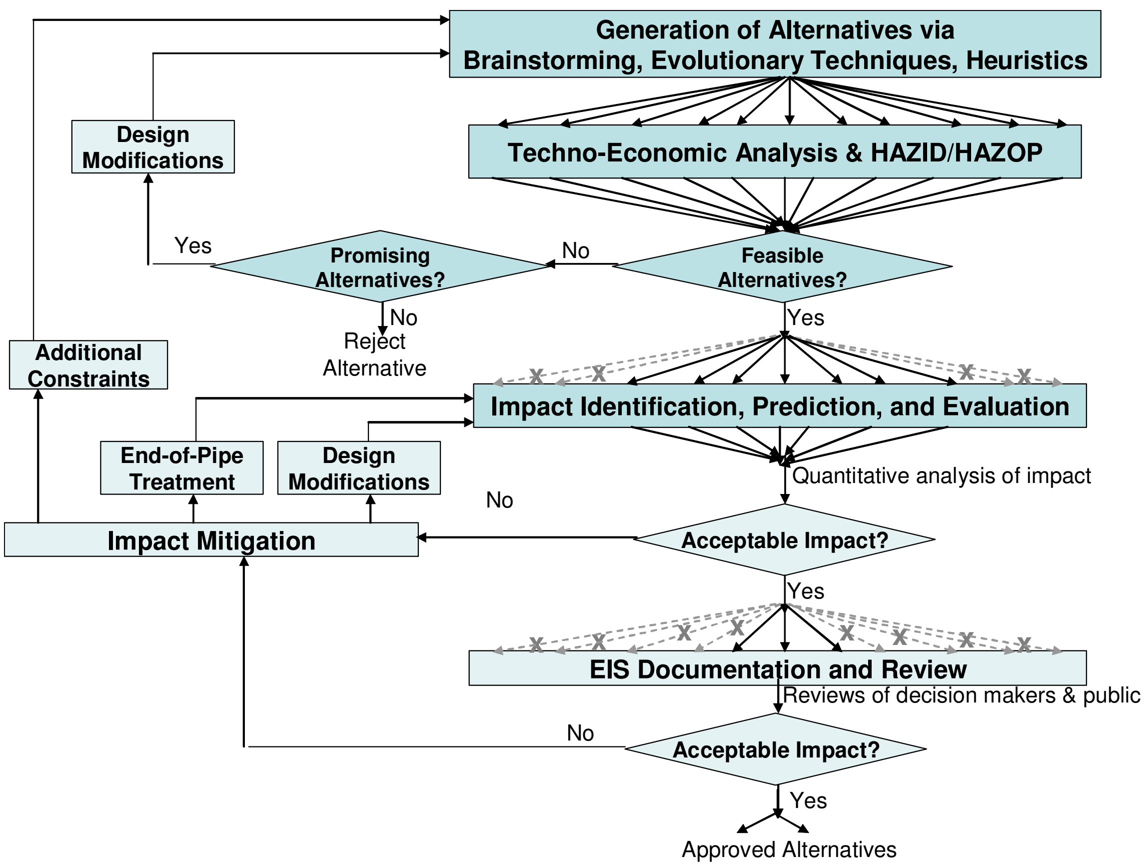

Fig. 2.2. Main Process Engineering Activities in EIA
(dotted lines designate alternatives)

II.3. WHAT IS PROCESS INTEGRATION?

Process integration is *a holistic approach to process design, retrofitting, and operation which emphasizes the unity of the process* (El-Halwagi, 1997). For recent reviews of process integration, the reader is referred to recent textbooks and literature (Kemp, 2007; El-Halwagi, 2006; Smith, 2005; Rossiter, 2004; Dunn, & El-Halwagi, 2003 ; Hallale, 2001; El-Halwagi & Spriggs,1998). Typically, process integration involves four key steps (El-Halwagi, 2006):

1. **Task Identification** which refers to the explicit expression of the design in terms of *actionable* tasks.

2. **Targeting**: The concept of targeting is one of the most powerful contributions of process integration. *Targeting refers to the identification of performance benchmarks ahead of detailed design.*

3. **Generation of Alternatives (Process Synthesis)**: Given the large number of possible solutions to reach the target (or the defined task), process synthesis techniques may be used to effectively identify those process alternatives that meet the target at minimum economic and environmental cost. Valuable process synthesis techniques exist for a variety of systems including reactions, separations, energy management and hybrids. Such techniques are described elsewhere in the literature (Seader et al., 2003; Biegler et al., 1997; Doherty & Malone, 2001; Lou et al., 2003; Linke & Kokossis, 2003a; Achenie & Biegler, 1998; Glasser & Hildebrandt, 1987; Heckl et al., 2005; Brendel et al., 2000; Johns, 2001; Uppaluri et al., 2006; Ashley & Linke, 2004; Papadopoulos & Linke, 2004; Linke & Kokossis, 2003b).

4. **Detailed Analysis of Selected Alternative(s):** Process analysis techniques (e.g., computer-aided simulation, safety analysis, etc.) may be employed to evaluate the generated alternative based on various performance metrics.

II.4. HOW CAN PROCESS INTEGRATION BE USED AS AN ENABLING TOOL FOR EIA?

We propose to use process integration as an instrumental tool for enabling and facilitating EIA through the following strategies:

1. Process synthesis for systematic generation of alternatives and targeting for benchmarking environmental impact ahead of detailed design
2. Reverse Problem Formulation
3. Integration of alternative with rest of the process

Here are details on the abovementioned strategies:

1. Process Synthesis for Systematic Generation of Alternatives and Targeting for Benchmarking Environmental Impact ahead of Detailed Design

Instead of brainstorming, heuristics, and evolutionary procedures, process synthesis techniques may be used to systematically generate process alternatives. The powerful concept of targeting is them applied to determine important benchmarks for the performance of the alternative. Examples of useful targets include:

- Flue gas minimization (Smith, 2005)
- Minimum waste discharge and fresh usage for recycle (El-Halwagi et al, 2003a; Noureldin & El-Halwagi, 2000)
- Hydrogen minimization (Alves & Tower, 2002)
- Wastewater minimization (Wang & Smith, 1994; Foo & Manan, 2006)

- Minimum VOC emission from a condensation system (Richburg & El-Halwagi, 1995)
- CO_2 minimization for utility systems (Linnhoff & Dhole, 1993)
- Minimum usage of external mass-separating agents (El-Halwagi & Manousiouthakis, 1989)
- Minimum heating and cooling utilities (Linnhoff & Hindmarsch, 1983)
- Maximum efficiency of reaction processes (Achenie & Biegler, 1998; Ashley & Linke, 2004)
- Maximum efficiency of integrated reaction and separation processes (Linke & Kokossis, 2003)
- Performance targets for solvent-based separation systems (Papadopoulos & Linke, 2006)

The advantage of such targets is that they can be evaluated for their environmental impact ahead of performing detailed design. As such, if the target is not environmentally acceptable, there is no need to detail the design and analysis of the alternative. The result is a more effective process and saving time and effort for the process engineers. Figure 2.3 is a representation of the proposed approach utilizing targeting and process synthesis.

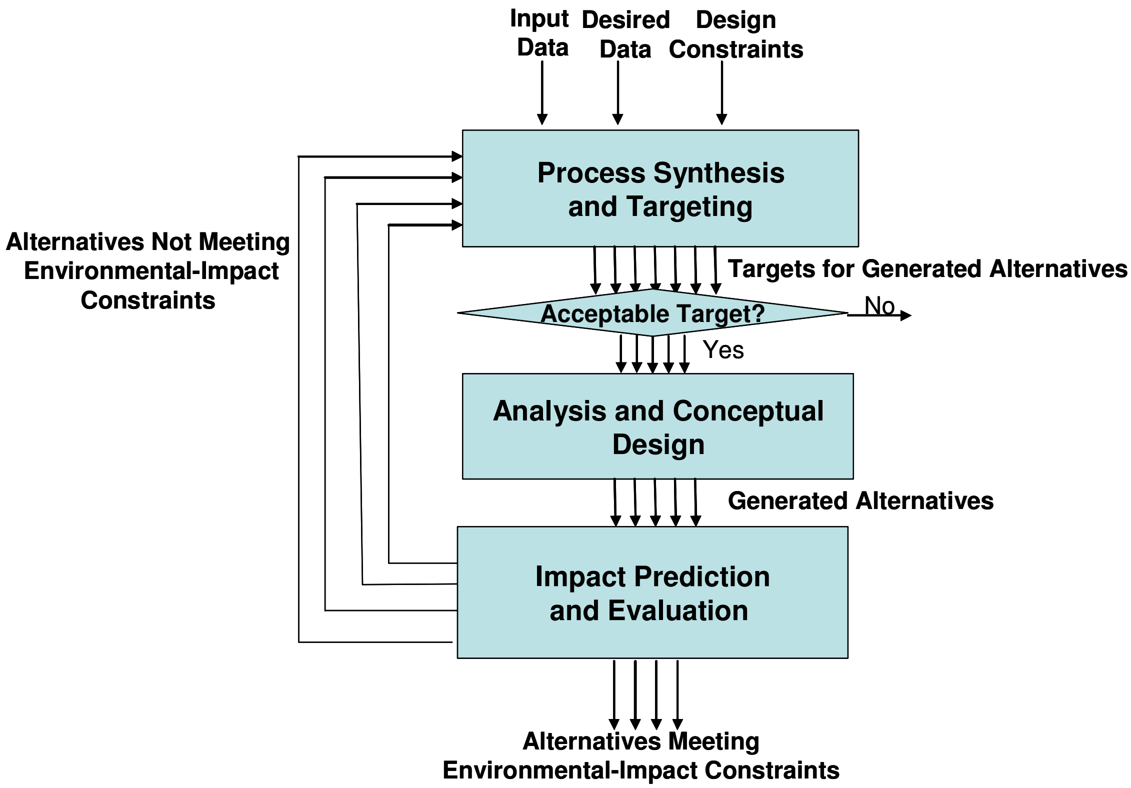

Fig. 2.3. Using Process Synthesis and Targeting in EIA

2. Reverse Problem Formulation

The forward problem for environmental prediction and evaluation quantitatively determines the spatial and temporal consequences of a certain alternative on the environment while taking into consideration the interaction with various environmental elements and other systems (e.g., neighboring plants, cities, etc.). In such cases, the discharges of the alternative are known but their impact on a specific element of the environment at a certain time is unknown. As mentioned earlier, various models and approaches may be used in impact prediction and evaluation such as atmospheric dispersion and water quality models (Arya, 1999; Martin & McCutcheon, 1998; El-Baz et al., 2005a) and , it is possible to identify a number of these which may be easily invertible (El-Baz et al., 2005b, Laird et al., 2005). Hence, for a given desired impact or constraints on the environment, the environmental prediction and evaluation model may be used to back-propagate the constraints and determine a target for the acceptable discharges of the alternative. This is referred to as the *reverse problem formulation.* Such formulations enable the incorporation of appropriate constraints into early process synthesis formulations so that optimum designs with acceptable environmental impacts can be developed from the start. The forward and reverse problems are represented by Fig. 2.4. Early incorporation of environmental issues (more than just environmental regulations because it includes interaction with neighboring system and spatial/temporal tracking of the discharges) into early design and generation of alternatives is quite beneficial from a design perspective. It insures that undesirable environmental consequences are included in the early phase of generating alternatives and that unsound alternatives are pre-empted early enough in the design cycle.

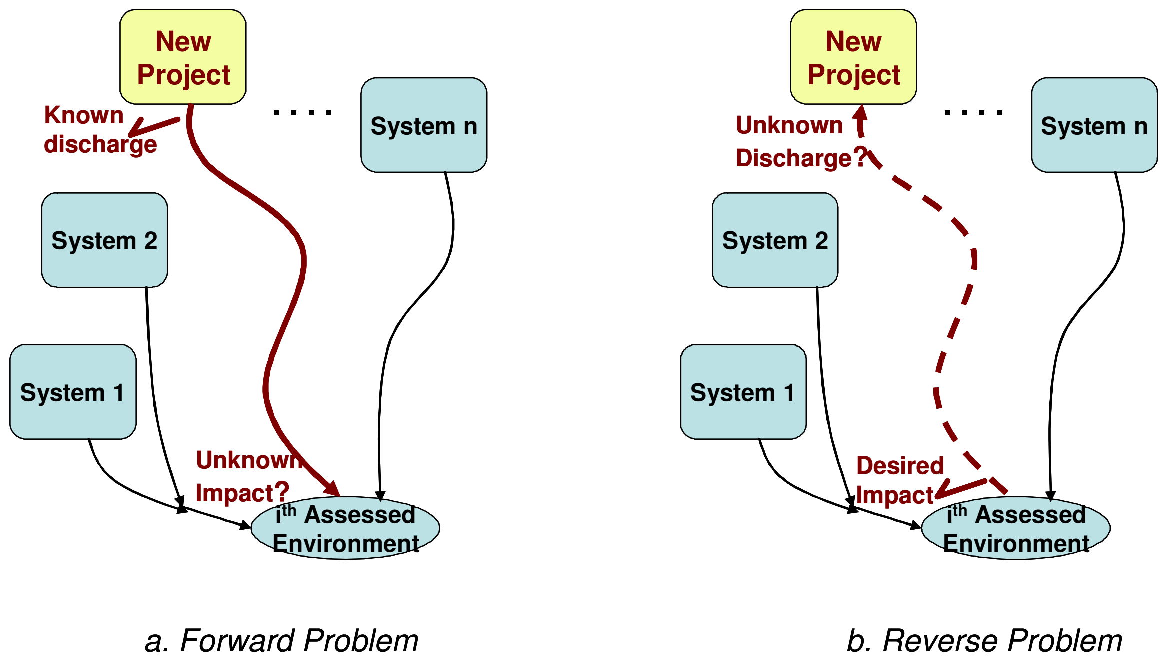

Fig. 2.4. Forward and Reverse Problems for Environmental Prediction and Evaluation

3. Integration of Alternative with Rest of the Process

When an alternative is deeded unacceptable during the EIA process, it is possible to mitigate undesirable consequences of this alternative by integrating it with the rest of the process. In other words, while the proposed alternative may not meet EIA review on its own, upon integration with the rest of the process, it might become acceptable. For instance, suppose that an alternative results in unacceptable thermal pollution. When this alternative is thermally integrated with the process (e.g., through the synthesis of a heat exchange network), the thermal pollution may be eliminated cost effectively by exchanging heat with process cold streams. This possibility could be explored by introducing appropriate constraints with respect to acceptable thermal pollution into the heat exchanger network synthesis problem formulation. Similarly, acceptable limits for other forms of pollution can be incorporated into process design and retrofit problem formulations to explore the possibility of achieving design alternatives with acceptable environmental impacts. It is worth noting that it is possible to encounter cases where integrating the alternative with the process not only mitigates negative environmental consequences but also improves the process profitability as a result of the associated efficiency gains. On the other hand, it is also possible to have situations where integrating the alternative with the process may not be economically justifiable on its own but when the environmental-mitigation objective is added, integrating the alternative becomes economically attractive.

II.5. CASE STUDY

Consider the Kraft pulping process (Lovelady et al., 2007) shown in Figure 2.5. The current production rate is 1200 tons per day (tpd) of bleached pulp. A new project is to be initiated to increase the capacity of the plant to 1500 tpd of bleached pulp. The plant has sufficient operating capacity to expand to a 1500 tpd production with one exception: There is a bottleneck at the brown stock washing area which is currently operating at full capacity. The process engineering team is considering three alternatives: (a) installation of an additional washer to accommodate a 200 tpd increase in production, (b) purchase of 300 tpd of unbleached pulp then feeding them to the existing bleach plant, or (c) building a smaller kraft mill to produce the additional 300 tpd. Based on economic analysis, the first alternative is pursued and an EIA study is initiated to understand and address the environmental consequences of the proposed solution. Particularly, there is a major concern about the discharge of chloride ions in the wastewater streams which impact a tributary that connects to a drainage system which eventually discharges in a lake. By applying the aforementioned reverse problem formulation using a watershed model (El-Baz, et al., 2005a), it is determined that the maximum allowable discharge load of chlorides from the plant is 12.7 tpd (compared to a projected discharge of 15.6 tpd following expansion). Therefore, focus is given to the reduction of the chloride discharge. Numerous dechlorination technologies are available for end-of-pipe treatment of the discharged wastewater. Before engaging in laborious techno-economic analysis of these dechlorination devices, the process engineers examine the target for in-process modification using a low/no cost strategy of direct recycle (without adding new process equipment, El-Halwagi, 2006). There are four recyclable sources: wastewater from screening, multiple effect evaporator, concentrator, and, bleach plant effluent. There are four sinks that employ fresh water: screening, brown stock washer, washers/filters and the bleach plant. Because of quality issues, recycle is not permitted to the bleach plant. Using mass integration techniques (El-Halwagi, 2006) and optimization coding using the software LINGO (please see Appendix A for more details), the target for minimum chloride discharge after direct recycle is found to be 15.146 tpd. This target is indeed attainable as illustrated by the flowsheet shown in Fig. 2.6.

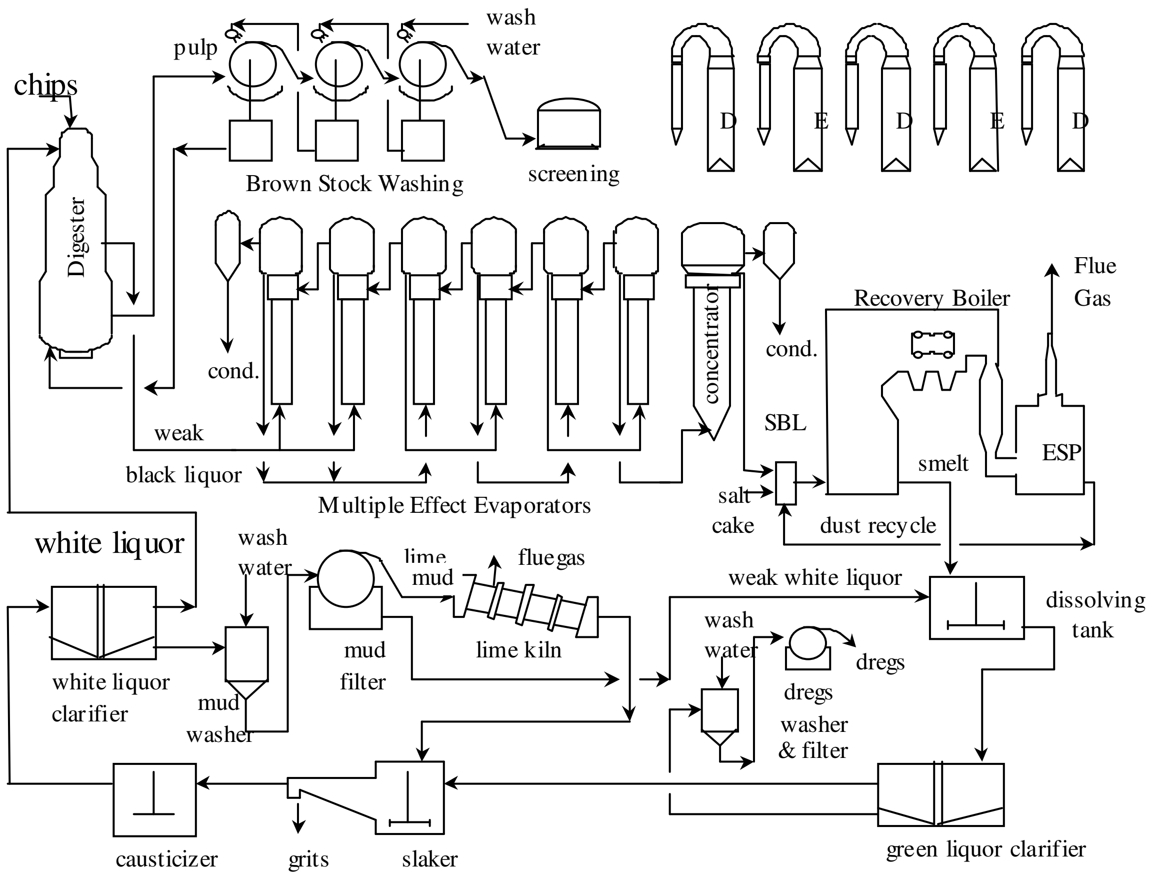

Fig. 2.5. A Pulp and Paper Process (Lovelady et al., 2007)

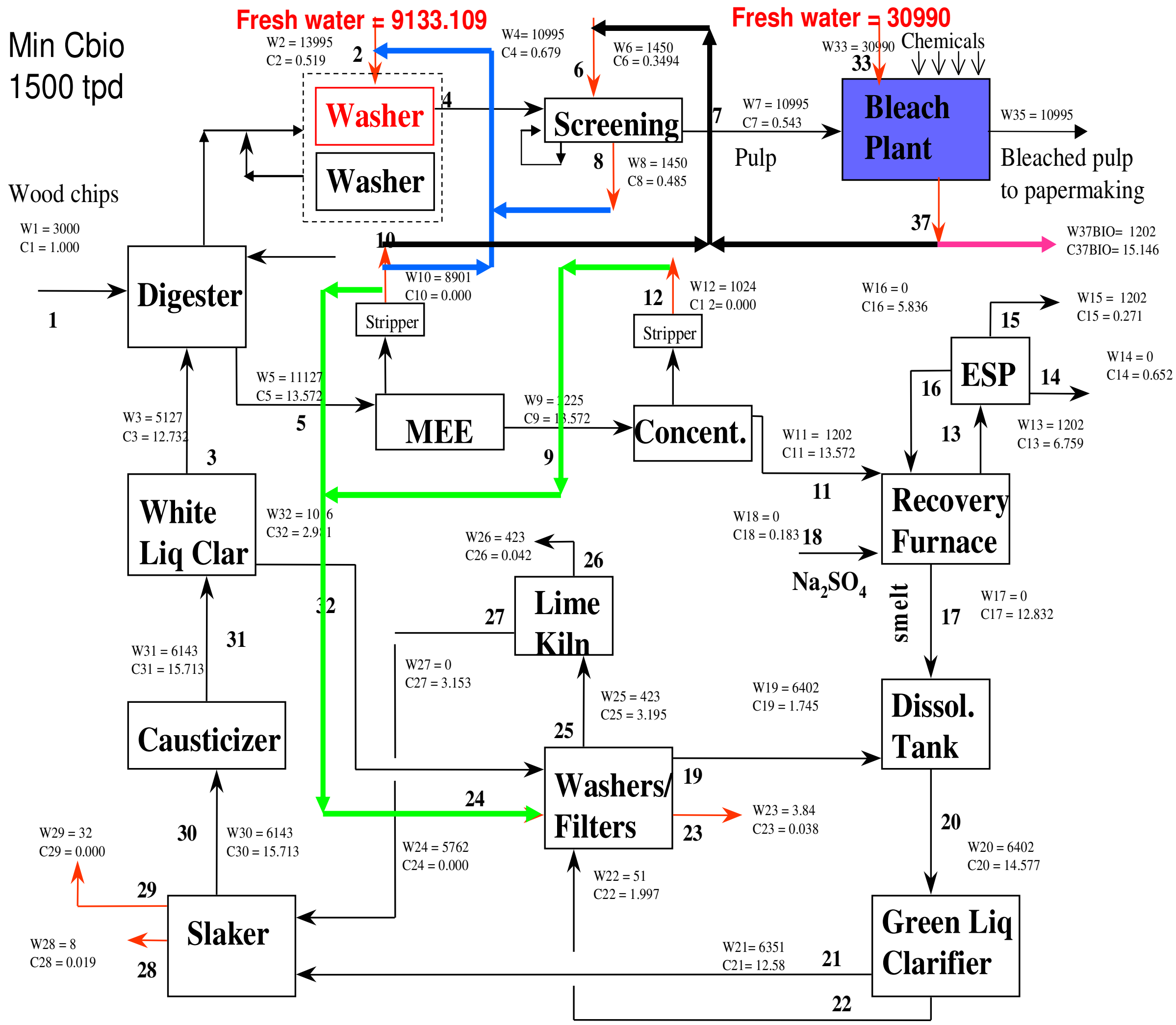

Fig 2.6. Integration Solution to 1500 tpd with Direct Recycle

II.6. CONCLUSIONS

This work has presented an integrated approach to EIA which offers the following advantages:

- Assisting the engineer in quickly generating and screening project alternatives
- Excluding non-promising candidates from the analysis early enough
- Accounting for explicit and implicit environmental constraints
- Accounting for compounded environmental effects
- Inverting environmental constraints to the process and using process integration techniques to make appropriate process changes
- Reducing the process engineering efforts, gaining valuable insights early enough in the process, and systematizing the design effort while reconciling the various process objectives with the environmental objectives.

CHAPTER III

REVERSE PROBLEM FORMULATION FOR INTEGRATING PROCESS DISCHARGES WITH WATERSHEDS AND DRAINAGE SYSTEMS: OPTIMIZATION FRAMEWORK AND APPLICATION TO MANAGING PHOSPHORUS IN LAKE MANZALA

III.1. INTRODUCTION

Watersheds and drainage systems are macroscopic environmental systems that provide a major impact on the Earth's ecology. A watershed covers a geographical region where water flows through various surface and underground drainage pathways. A watershed typically involves a number of tributaries that feed into reaches, streams, or rivers that finally lead to catchment areas such as lakes, seas, and oceans. Watersheds are impacted by surrounding inputs such as agricultural, residential, and industrial systems. On the other hand, watersheds provide a major impact on the various biological, physical, health, and social components of the surrounding environmental systems. In order to understand the characteristics of watersheds, how they are impacted by their surroundings, and how they impact their surroundings, it is important to develop quantitative models that track the flows and compositions of various pollutants throughout the watershed. In this regard, a particularly useful tool material flow analysis (MFA). The key objective of MFA is track targeted species and analyze causes for pollution problems in a certain region by accounting for all relevant activities, water sources, water users, pollution sources, and physical/chemical/biological phenomena impacting the watershed. Baccini and Brunner (1991) developed an MFA model for analyzing ecosystems with human activities where mass, energy, and information are being exchanged with the surroundings. Lampert and Brunner (1999) used MFA to track principal nutrients discharges, transformation, and flows into the river Danube basin. El-Baz et al. (2005a) developed an MFA model for watersheds and applied it to Bahr El-Baqar drainage system for tracking nitrogenous compounds.

It is worth noting that MFA models and other forms of environmental quality models are carried out in the ***forward mode***, i.e. a given scenario is posed and its consequences are tracked via the MFA. For instance, suppose that a new industrial facility is to be installed on a watershed. The exact location is to be determined. Also, in addition to satisfying the environmental regulations for the process discharges, it is necessary to examine the impact of the process effluents on the watershed. As an illustration, consider the case shown in Fig. 3.1. A new industrial facility is to be installed on a watershed. The process has certain process discharges with a given composition of a certain pollutant, $y^{Process}$. It is important to analyze how the installation of this plant interacts with the rest of the watershed (including other sources and users such as agricultural usage and discharge, wastewater treatment plant, residential usage and discharge, etc.). It is also necessary to assess the impact of the process discharge on the receiving lake. These aspects are also central to any environmental impact assessment of the new plant. In the usual MFA forward mode, a construction site will be selected and the MFA model will be used to track the process discharge throughout the watershed. If the discharge to the lake is acceptable, the environmental discharge of the process is deemed satisfactory. Otherwise, a laborious trial-and-error procedure is adopted to modify the plant design, environmental system, and location until an acceptable discharge to the lake is achieved.

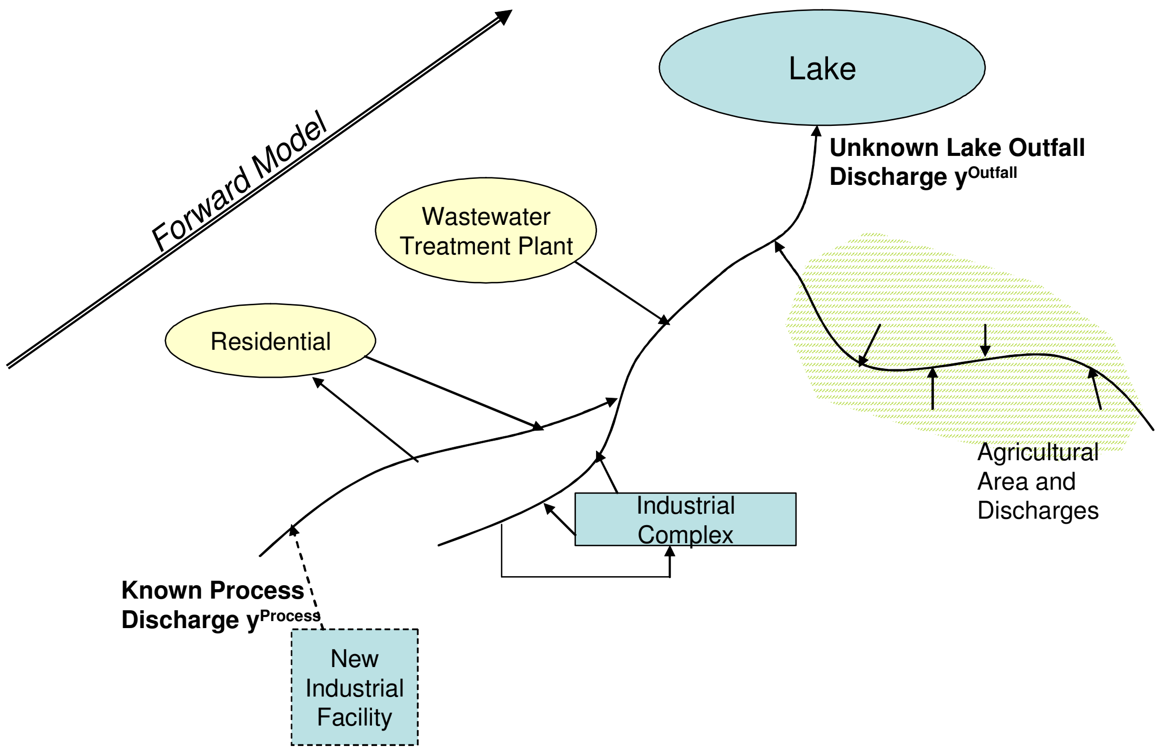

Fig. 3.1. Forward Model for Tracking Discharges of a New Process

The main theme of this work is to introduce an inverse approach to targeting acceptable discharge of the process while integrating the process effluents with the rest of the watershed. The approach is referred to as ***reverse problem formulation***. This approach starts "with the end in mind." Therefore, the desired characteristics of the discharge to the lake are first specified. Then, the MFA model is included in an optimization formulation that seeks to determine the maximum acceptable discharge from the process that will have an acceptable impact on the lake while accounting for all interactions throughout the watershed. Figure 3.2 is a schematic representation of the reverse problem formulation. This work introduces the theoretical formulation for this approach. It also provides an application case study in for managing phosphorus compounds in Bahr El-Baqar watershed leading to Lake Manzala. First, the basic equations for an MFA model are presented. Then, the optimization formulation for reverse problem formulation is introduced. Next, the case study is discussed. The results of the case study are compared with actual measurements. Finally, the problem of plant location and environmental targets is solved.

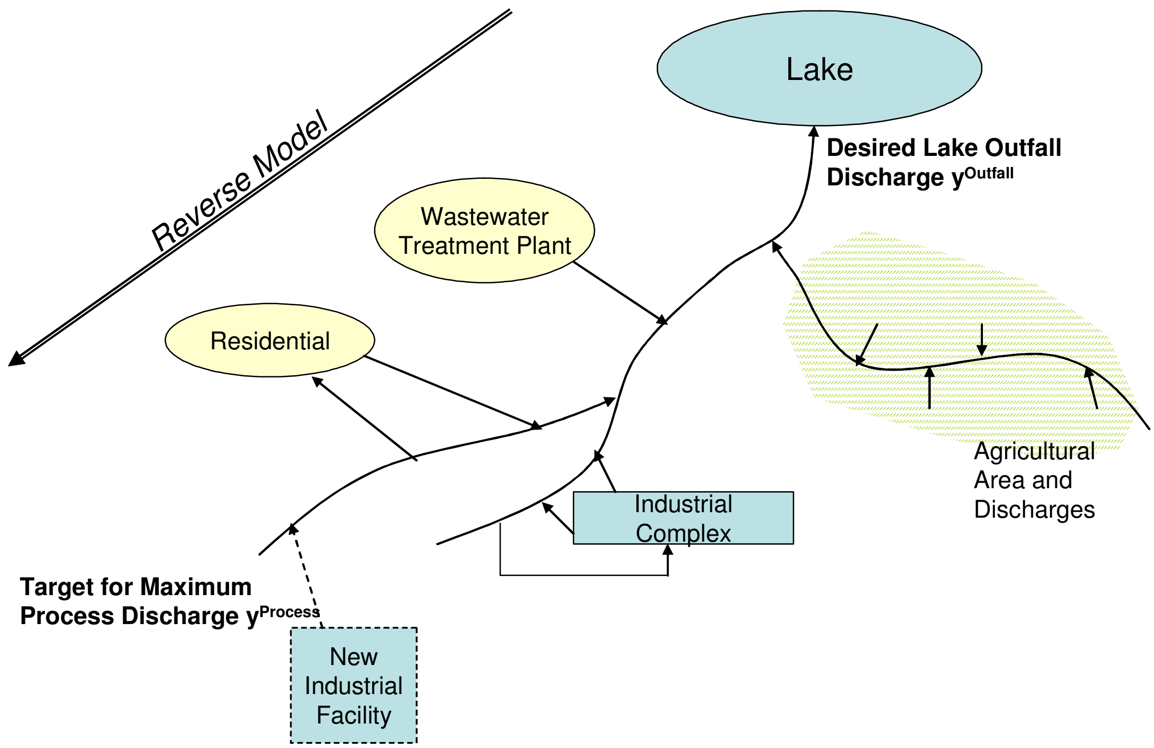

Fig. 3.2. Inverse Approach to Integrating the Process and the Watershed

III.2. PROBLEM STATEMENT

Consider a watershed system with its tributaries and reaches. Various input and outputs are associated with the watershed. These include P agricultural drainage, treated and untreated wastewater, industrial effluents, and precipitation. System outflows include discharge to lakes and waterways, seepage, and vaporization. Throughout the watershed, there are chemical and biochemical reactions that lead to transformation of discharged pollutants and formation of byproducts. The system surroundings include a given set of wastewater treatment plants, residential, agricultural, and industrial sectors. The catchment of the watershed (e.g., lake) has desired characteristics for the discharge (e.g., at the lake outfall). A new industrial facility is to be installed on the watershed. It is desired to determined optimal plant location and maximum allowable discharge of the process such that the environmental requirements of the watershed are met.

To address the aforementioned problem, this work provides two new contributions:

1. Development of a reverse problem formulation for the MFA model to determine the maximum allowable target for the process discharge while satisfying the desired environmental performance of the watershed.
2. Application of the devised approach to managing phosphorus ions in Bahr El-Baqar drain system leading to Lake Manzala in Egypt.

III.3. MFA MODELING EQUATIONS

This work adopts the MFA modeling equations developed by El-Baz et al. (2005a). The key equations are given by:

III.3.1 Flowrate Balance for the Reaches

$$Q_{i,t} = Q_{i-1,t} + P_{i,t} + D_{i,t} + H_{i,t} + \sum_{j=1}^{N_{Trib,i}} T_{j,i,t} - L_{i,t} - U_{i,t} \qquad (3.1)$$

Where

$Q_{i,t}$ = Flowrate leaving the ith reach, m^3/s

$Q_{i-1,t}$ = Flowrate entering the ith reach, m^3/s

$P_{i,t}$ = Precipitation flow to the ith reach, m^3/s

$L_{i,t}$ = Net losses from the ith reach (e.g., seepage, vaporization, use, etc.), m^3/s

$D_{i,t}$ = Non-tributary direct discharge to the ith reach, m^3/s

$H_{i,t}$ = Total discharge to (e.g., industrial discharge + sanitary discharge, etc.) to the reach m^3/sec

$T_{j,i,t}$ = Tributary discharge from the jth tributary to the ith reach, m^3/s.

$U_{i,t}$ = Usage discharge from the reach ith, m^3/sec.

III.3.2 Pollutant Balance for the Reaches

$$Q_{i,t} * CQ_{i,t} = Q_{i-1,t} * CQ_{i-1,t} + H_{i,t} * CH_{i,t} + P_{i,t} * CP_{i,t} + D_{i,t} * CD_{i,t} + \sum_{j=1}^{N_{Trib,i}} T_{j,it} * CT_{j,i,t} - L_{i,t} * CL_{i,t} - U_{i,t} * CU_{i,t} - \int_{V=0}^{V_{i,t}} r_{i,t}\ dV_{i,t} \tag{3.2}$$

where

$Q_{i,t} * CQ_{i,t}$ = Load rate leaving the reach via convective flow (where $CQ_{i,t}$ is the component concentration in the convective stream leaving reach i)

$Q_{i-1,t} * CQ_{i-1,t}$ = Load rate entering the reach via convective flow

$H_{i,t} * CH_{i,t}$ = Total load rate of discharges (e.g., industrial discharge + sanitary discharge, etc. over reach I

$P_{i,t} * CP_{i,t}$ = Total load rate of precipitation over reach i

$D_{i,t} * CD_{i,t}$ = Total load rate of drainage over reach i

$L_{i,t}*CL_{i,t}$ = Total load of losses (e.g., seepage and vaporization) over reach i

$U_{i,t}*CU_{i,t}$ = Total load of usage over reach i

For a first-order reaction the expression becomes:

$$\int_{V=0}^{V_{i,t}} r_{i,t}\ dV_{i,t} = k_{i,t} * CQ_{i,t} * V_{i,t} \tag{3.3}$$

Where $k_{i,\ t}$ is the Arrhenius reaction rate constant. Hence,

$$Q_{i,t} * CQ_{i,t} = Q_{i-1,t} * CQ_{i-1,t} + H_{i,t} * CH_{i,t} + P_{i,t} * CP_{i,t} + D_{i,t} * CD_{i,t} + \sum_{j=1}^{N_{Trib,i}} T_{j,it} * CT_{j,i,t} - L_{i,t} * CL_{i,t} - U_{i,t} * CU_{i,t} - k_{i,t} * CQ_{i,t} * V\ dV_{i,t} \tag{3.4}$$

III.3.3 Pollutant Balance for the Tributaries

$$T_{j,i,t} * CT_{j,i,t} = S_{j,i,t}^{untreated} * CS_{j,i,t}^{untreated} + S_{j,i,t}^{treated} * CS_{j,i,t}^{treated} + I_{j,i,t} * CI_{j,i,t} + P_{j,i,t} * CP_{j,i,t} + D_{j,i,t} * CD_{j,i,t} - L_{j,i,t} * CL_{j,i,t} - U_{j,i,t} * CU_{j,i,t} - r_{j,i,t} * V_{j,i,t} \tag{3.5}$$

Where

$S_{j,i,t}^{untreated}$ = Untreated sewage (sanitary waste) discharged to the j^{th} tributary, m^3/s

$S_{j,i,t}^{treated}$ = Treated sewage (sanitary waste) discharged to the j^{th} tributary, m^3/s

$I_{j,\ j,\ t}$ = Industrial flow of wastewater discharged to the j^{th} tributary, m^3/s.

$P_{j,i,t}$ = Precipitation flow discharged to the j^{th} tributary, m^3/sec.

$L_{j,i,t}$ = Net losses from the j^{th} tributary (e.g., seepage, vaporization, use, etc.), m^3/s

$D_{j,\ i,\ t}$ = Agricultural drainage discharged to the j^{th} tributary, m^3/s

To simplify the terminology for modeling the reaches and tributaries, over a given averaged time period these equations are rewritten as:

$$(Q_u, y_u) = \psi_u(Q_u^{in}, y_u^{in}, I_u^{in}, C_u^{in}) \tag{3.6}$$

where u is an index used for all tributaries and reaches. Also, Q_u and y_u are flowrate and composition leaving the u^{th} reach or tributary. It is described as a function of the vector of all reaches and tributaries feeding into u. These flowrates and compositions are given by the vectors Q_u^{in} and y_u^{in}. Additionally, the equation accounts for all inputs from the surroundings (e.g., residential, industrial, agricultural) given by the flowrate and composition vectors I_u^{in} and C_u^{in}.

Consider a new plant to be installed at location $\bar{\bar{u}}$. The flowrate and composition of the process effluent are designated as: $P_{\bar{u}}$ and $y_{\bar{u}}^{\Pr ocess}$. Therefore, the MFA model at location $\bar{\bar{u}}$ can be modified as follows:

$$(Q_{\bar{u}}, y_{\bar{u}}) = \psi_{\bar{u}}(Q_{\bar{u}}^{in}, y_{\bar{u}}^{in}, I_{\bar{u}}^{in}, C_{\bar{u}}^{in}, P_{\bar{u}}, y_{\bar{u}}^{\Pr ocess}) \tag{3.7}$$

This expression can be inverted to have $y_{\bar{u}}^{\Pr ocess}$ on the left-hand side, i.e.

$$y_{\bar{u}}^{\Pr ocess} = (\Omega_{\bar{u}}(Q_{\bar{u}}, y_{\bar{u}}, Q_{\bar{u}}^{in}, y_{\bar{u}}^{in}, I_{\bar{u}}^{in}, C_{\bar{u}}^{in}, P_{\bar{u}}) \tag{3.8}$$

The desired composition at the outfall is given by $y^{\text{Outfall, desired}}$.

The reverse problem formulation seeks to find the maximum allowable composition of the process effluent while including the modeling equations for the whole watershed using the MFA and the inverted equation relating the process effluent to the various inputs and outputs while satisfying the discharge targets at the outfall. Mathematically, the problem can be posed as an optimization formulation as follows:

Maximize $y_u^{\Pr ocess}$

Subject to:

$$(Q_u, y_u) = \psi_u(Q_u^{in}, y_u^{in}, I_u^{in}, C_u^{in}) \qquad \forall u \neq \bar{u}$$

$$y_{\bar{u}}^{\Pr ocess} = (\Omega_{\bar{u}}(Q_{\bar{u}}, y_{\bar{u}}, Q_{\bar{u}}^{in}, y_{\bar{u}}^{in}, I_{\bar{u}}^{in}, C_{\bar{u}}^{in}, P_{\bar{u}})$$

$$y^{outfall} \leq y^{Outfall, desired}$$

The solution determines the target composition for the maximum allowable process effluent and provides the revised data for the watershed reaches and tributaries as a result of placing the plant at location $\bar{u}$.

III.4. CASE STUDY: MANAGING PHOSPHORUS IN BAHR EL-BAQAR DRAINAGE SYSTEM AND LAKE MANZALA

III.4.1. Overview of Bahr El-Baqar Drainage System

Bahr El-Baqar drain is one of the largest drains east of the Nile Delta in Egypt. The starting point originates from the intersection point of Qalyoubia drain and Belbies drain that start from the northern part of greater Cairo. Its end point is the inlet of the southern part of Lake Manzala (Fig. 3.3). The drain has a length of 106.5 km and with a bed width ranged from 23 m at the start point and up to 70 m at the end point with a side slope of 2:1

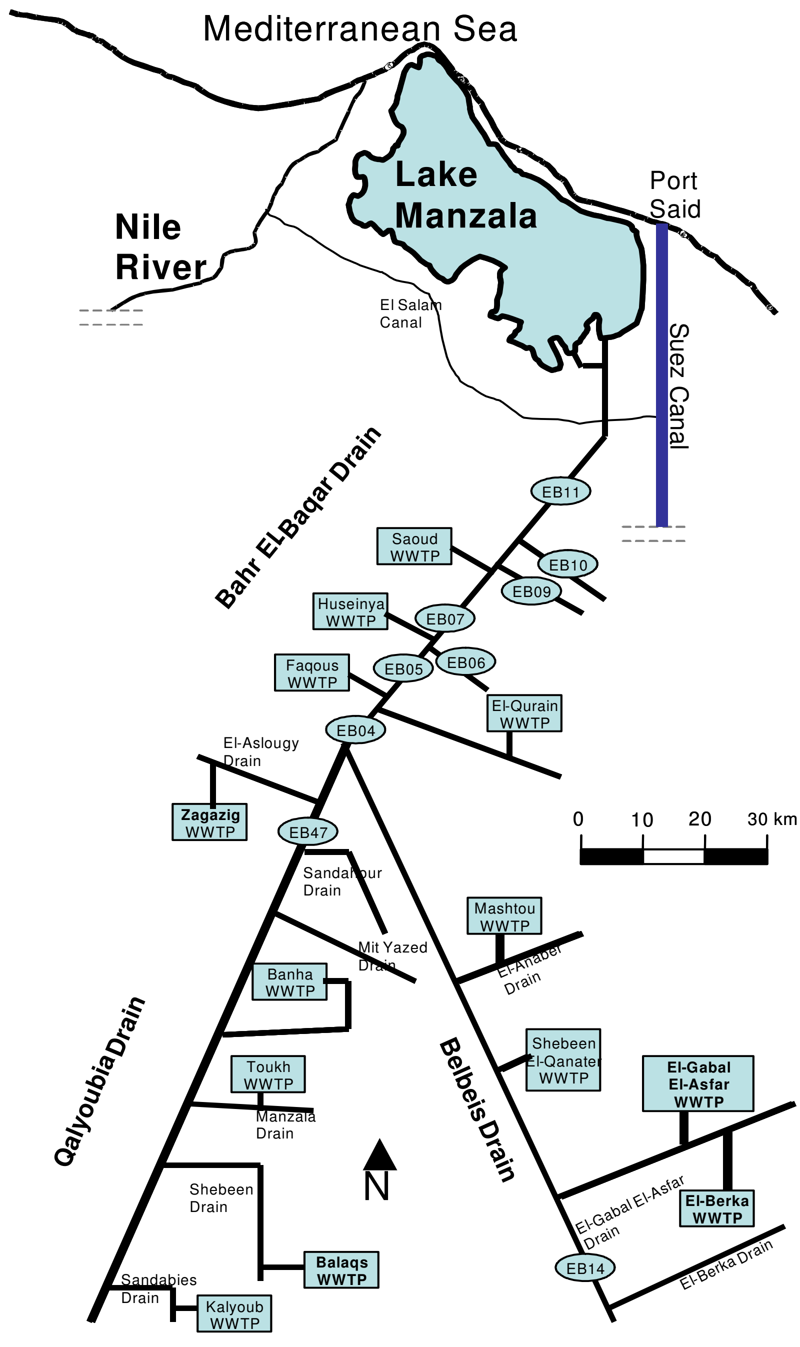

Fig. 3.3. Schematic Representation of Bahr El-Baqar Drainage System and Lake Manzala

The drain receives several types of discharges including agricultural drainage, treated and untreated domestic wastewater, and industrial wastewater. The agricultural drainage and the domestic wastewater are considered the two major sources of discharges contributing significantly to the flow in the drain. The industrial wastewater is primarily discharged from the industrial zone of Shoubra El-Khima in Cairo through Sheben El-Qanater drain. The discharges from agricultural drainage are received from the surrounding areas. Along the drains are some drainage pump station that are established by the Egyptian Ministry of Water Resources and Irrigation to collect water from the drains network and raise it by pumping stations into Bahr El-Baqar drain. There are two types of reuse from the drain: official and unofficial. The official reuse is regulated by the Egyptian Ministry of Water Resources and Irrigation using irrigation pump stations to compensate for the seasonal shortage of water resources. The unofficial reuse is practiced by farmers along Bahr El-Baqar watershed. As the domestic and the agricultural drainage are the main contributors to the flow in the drain they will be described as follows:

a) Domestic Wastewater: Belbeis and Qalyoubia drains are the two major drains carrying the wastewater from Cairo discharge to Bahr El-Baqar drain. Belbies drain receives wastewater from two wastewater treatment plants on the east bank of Cairo: El-Gabal El-Asfar and El-Berka. Additionally, domestic wastewater is discharged from urban as well as rural areas along the drain. On the other hand, Qalyoubia drain carries wastewater from Shoubra El-Kheima via Balaqs wastewater treatment plant in addition to the wastewater from the urban as well as rural areas along the drain.

b) Agricultural Drainage: Three catchments of agricultural areas contribute to the agricultural drainage runoff in Bahr El-Baqar drain. Qalyoubia catchment's area serves almost 288,200 feddan , Belbies drain serves an area of almost 90,000 feddan, and Bahr El-Baqar drain is estimated to serve an area of almost 616,040 feddan. The agricultural drainage contributing to the flow in the main drains is caused by either the tributaries or direct discharge to theses drains. Vegetables are the dominant plants along the Qalyoubia drains near Cairo while other crops like rice, wheat, maize, alfalfa, etc are distributed along the watershed. Traditional crops such as rice, wheat, cotton, alfalfa, etc are the dominant plants along both Belbies and Bahr El-Baqar drain in addition to the vegetables.

III.4.2. Phosphorus Transformations in Water Systems

Phosphorus is a key component for all living organisms, found in vital nucleic acids, DNA and RNA, and providing energy transfer in the form of ATP. Through photosynthesis, plants utilize phosphorus, along with other important nutrients to build their tissues. On a global scale, phosphorus is the 10th most abundant element on Earth, existing in both terrestrial and aquatic systems. In terrestrial systems, it is found in bound form, contained in sediment rocks, soil, dead organics and living organisms. In aquatic systems, it is found in aquatic organisms, plants, particulate matter and sediments. Phosphorus is found in both dissolved and particulate organic/inorganic forms that can be uptaken by phytoplankton, settle to the bottom as sediment or undergo transformation through chemical and physical reactions to be recycled once more through the water column.

Phosphorus is a source of concern for the water quality in Lake Manzala. Excessive presence of phosphorus leads to eutrophication of the waters ecosystem. Eutrophication (Garnier et al., 2005; Jarvie et al., 2006; Malmaeus et al., 2006) promotes the growth of phytoplankton and other algal plants leading to increased water pollution which can have detrimental impacts in the marine system such as:

1. Increased phytoplankton/ algal plant growth and decay
2. Depletion of dissolved oxygen
3. Reduction of water quality
4. Decrease in resource value of rivers, lakes and estuaries, such as death of aquatic life(which in turn negatively impacts recreation activities0
5. Impact in taste, odor and water treatment

Phosphorus enters the water pool via point and non-point sources (e.g. Garnier et al., 2005; Jarvie et al., 2006; Malmaeus et al., 2006; De Laender et al., 2007; Bowes et al., 2008). Point sources are those which can be quantified and attributed to one source, such as urban effluent from wastewater treatment plants. Non-point sources, such as soil erosion, are those which cannot be easily attributed to one source and are more difficult to quantify. Table 3.1 summarizes the sources of phosphorus entering the drainage system.

TABLE 3.1
Sources of Phosphorus Entering the Drainage System

Point Sources	**Non-Point Sources**
Wastewater effluent	Runoff from agriculture
Runoff/leachate from waste disposal systems	Runoff from pastures/ranges
Runoff from animal feedlot	Urban runoff from unsewered areas
Runoff from untreated industry effluent	Leachate from septic tanks
Overflow of storm and sanitary sewers	Atmospheric deposition
Runoff from construction sites	Soil Erosion

In water, phosphorus is present in dissolved and particulate forms as a result of numerous biological and chemical transformations. Each form contains both organic and inorganic phosphorus. However, only dissolved inorganic phosphate (DIP) can be taken up by algae and phytoplankton, which are the prime causes for eutrophication. All other phosphorus forms of phosphorus undergo various transformations to DIP, which can then be taken up by biotic and abiotic organisms. Key steps in phosphorus transformation (Malmaeus et al., 2006; Smith et al., 1999; Maurer & Boller, 1999; Nausch et al., 2004; Ruley & Rusch, 2004; Paytan & McLaughlin, 2007; Chao et al., 2007; Zhou et al., 2007) are:

1. Photosynthetic Uptake
2. Respiration (Excretion)
3. Chemical Transformation
4. Hydrolysis of organic phosphorus
5. Decomposition of Particulate Organic Phosphorus
6. Sediment Decomposition

Photosynthesis (Soluble Reactive Phosphorus, SRP, uptake)

In photosynthesis, O_2 is released by phytoplankton and dissolved inorganic phosphorus is taken up through the following reaction:

$$106\ CO_2 + 64\ H_20 + 16\ NH_3 + H_3PO4 \rightarrow C_{106}H_{179}O_{68}N_{16}P + 106\ O_2$$

Respiration (SRP release/excretion)

DIP is released into the water column through respiration of phytoplankton. During respiration, phytoplankton utilized O2 and release CO2

$$C_{106}H_{179}O_{68}N_{16}P + 106\ O_2 \rightarrow 106\ CO_2 + 64\ H_20 + 16\ NH_3 + H_3PO4$$

Other fish and benthic organisms also release phosphorus through a similar pathway.

Decomposition of Particulate Organic Phosphorus and Hydrolysis of Dissolved Organic Phosphorus (conversion to SRP)

Organic phosphorus (OP), which consists of living and dead phytoplankton, phosphorus precipitates and phosphorus adsorbed onto particulates, is not directly available for uptake into phytoplankton. It must first undergo hydrolysis, which converts DOP to DIP. It should be recalled that organic phosphorus consists of particulate organic phosphorus (POP) and dissolved organic phosphorus (DOP). POP is converted to DOP through decomposition, which then undergoes hydrolysis to DIP.

POP = Plant death + POP settling – decomposition of organic matter
DOP = decomposition of POP – hydrolysis of DOP + plant excretion & death + dissolved sediment flux

Sedimentation and Sediment Release

Both organic and inorganic phosphorus can move between the water column and the sediment through adsorption/desorption onto particulate matter. In addition, decomposition of organic matter (plant) increases organic phosphorus. Particulate organic matter (POM), dead algal/plankton organism and other suspended organic matter settles to the bottom as sediment and can decay later on into DIP, which will released into the water column to be taken up by phytoplankton, etc.

III.4.3. Development of the MFA Model for Bahr El-Baqar Drainage System

In developing the MFA mathematical model, the following assumptions were invoked for the numerical data of some elements of the system:

1. Negligible rain: The precipitation flow value (P) was neglected according to the nature of weather in Egypt.
2. Negligible losses: The losses (L) including seepage, and vaporization were assumed to be much smaller than the convective flow.
3. The concentration of the phosphorus in the effluent from the WWTP was taken

to be 9 mg/l. This assumption is based on the laboratory analysis of different WWTP in Egypt such as El Gabal el Asfar and Zenein WWTP.

4. The phosphorus concentration in the untreated sewage (SU) in rural Egypt was taken to be 15 mg/l.
5. The phosphorus concentration for wastewater primary treated was taken as 9.75 mg/l as this value considers the removal of phosphorus concentration after secondary stage to be approximately 35 %.
6. The agricultural drainage concentration (CD) was taken as 1.5 mg/l.

III.4.4. MFA Model Validation and Results

Based on Eqs. 1-5, the MFA model was developed for all tributaries and reaches in Bahr El-Baqar drainage system. Only one fitting parameter was used which represents the kinetic rate constant. It was evaluated to be 0.78 day^{-1} by minimizing the error squared (of the model prediction versus the measured value) of phosphorus concentration at the Lake Manzala outfall. The model was coded using the software LINGO. Next, the model results were compared with measurements of phosphorus compositions over nine monitoring stations. The locations and description of these stations are provided in Table 3.2. These monitoring stations are shown in Fig. 3.3 by the designation EB followed by the station number.

TABLE 3.2 Codes of Different Monitoring Stations Along Bahr El-Baqar Drain		
Catchment Name	**Location_ Name**	**Location_Code**
Bahr El Baqar drain	Wadi Railway Bridge km 106	EB04
Bahr El Baqar drain	Saada Bridge km 75.700	EB05
Bahr El Baqar drain	Saada P.S. km 67.330	EB06
Bahr El Baqar drain	Saoud Bridge km 52	EB07
Bahr El Baqar drain	Bahr El Baqar Irrigation P.S. km 42.700	EB09
Bahr El Baqar drain	Bahr El Baqar P.S. 43.150	EB10
Bahr El Baqar drain	Bahr El Baqar Outfall km 20.260	EB11
Belbies drain	Belbies South P.S. km 58.80	EB14
Qalyoubia drain	Sandanhour mixed with Qalyoubia km 6.600	EB47

Figure 3.4 represents the model results of phosphorus concentration versus the measurements at the monitoring station. The results show good agreement between the measurements and the calculations at most of the monitoring station.

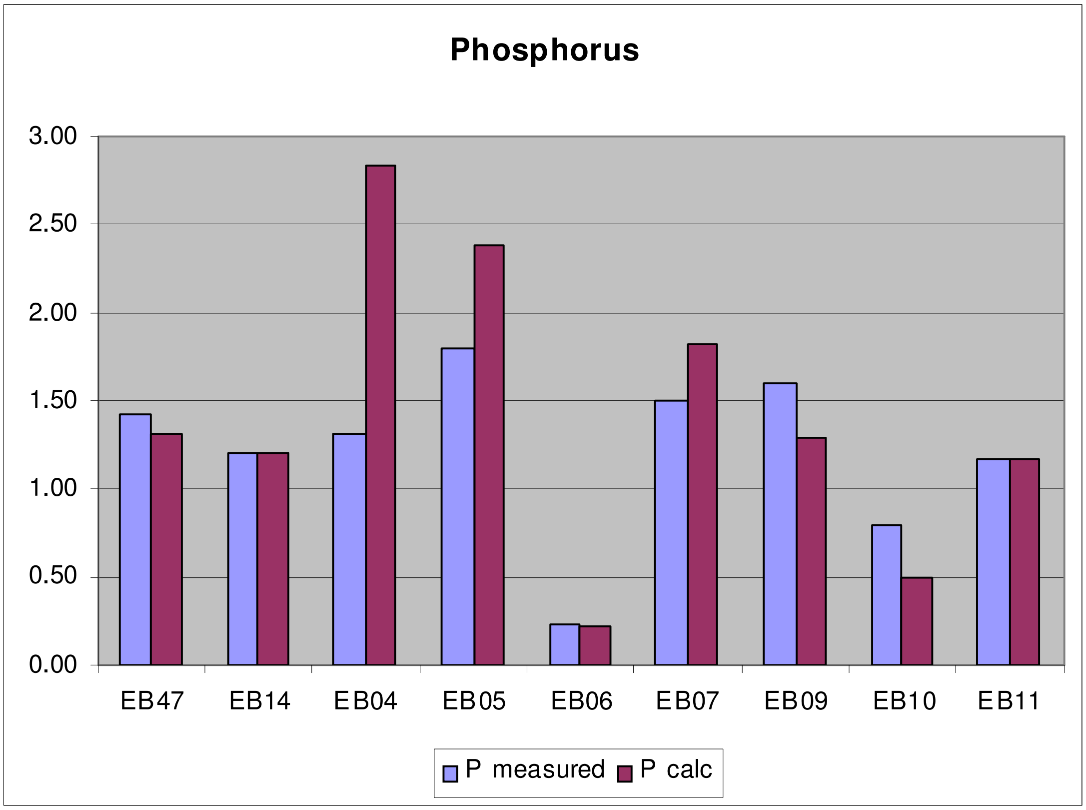

Fig. 3.4. Comparison between Model Results and Measurements

(vertical axis: phosphorus composition mg/l, horizontal axis: monitoring station)

III.4.5. Reverse Problem Formulation

Next in the case study, we consider the reverse problem formulation for the environmental impact of an industrial process. A new fertilizer plant is to be built in one of four possible locations discharging into Bahr El-Baqar drain. As part of the environmental impact assessment, it is required to determine whether or not the process effluents will have an acceptable impact on phosphorus discharge into Lake Manzala. Also, given that different plant locations will have different environmental impact and may entail different treatment costs, the company is interested in comparing the costs associated with the four candidate locations. Sites 1 and 2 are located on the Bahr El Baqar drain and will discharge into reaches 15 and 12, respectively. Site 3 is located on Belbeis Drain and will discharge into reach 10, while Site 3 will discharge into reach 4 on the Qalyoubia drain. Figure 3.4 shows the locations of the four candidate sites.

The fertilizer plant will discharge an effluent with a flowrate of 2.0 m^3/s containing a phosphorus concentration of 12.5 ppm. To prevent eutrophication, the phosphorus input to Lake Manzala cannot exceed 1.3 ppm. As a result, any potential location that discharges phosphorus which leads to an increase in the final watershed input above the allowable concentration will need to employ interception (phosphorus removal unit) at a cost of $21/kg of P removed. Two costs are to be considered for comparison: phosphorus treatment cost (using interception devices to lower phosphorus composition to an acceptable level) and cost of land. The land cost (annualized over the useful life period of the project) for each site is listed in Table 3.3. Thus, it is desired to determine the optimal site location for the fertilizer plant . The objective of the reverse problem formulation is to maximize the phosphorus concentration in the fertilizer plant effluent subject to land costs, removal costs, and final watershed P concentration to Lake Manzala.

TABLE 3.3
Annualized Land Cost for the Four Candidate Plant Locations

Candidate Location	Land Cost $ MM/yr
Site I	10
Site II	17
Site III	35
Site IV	18

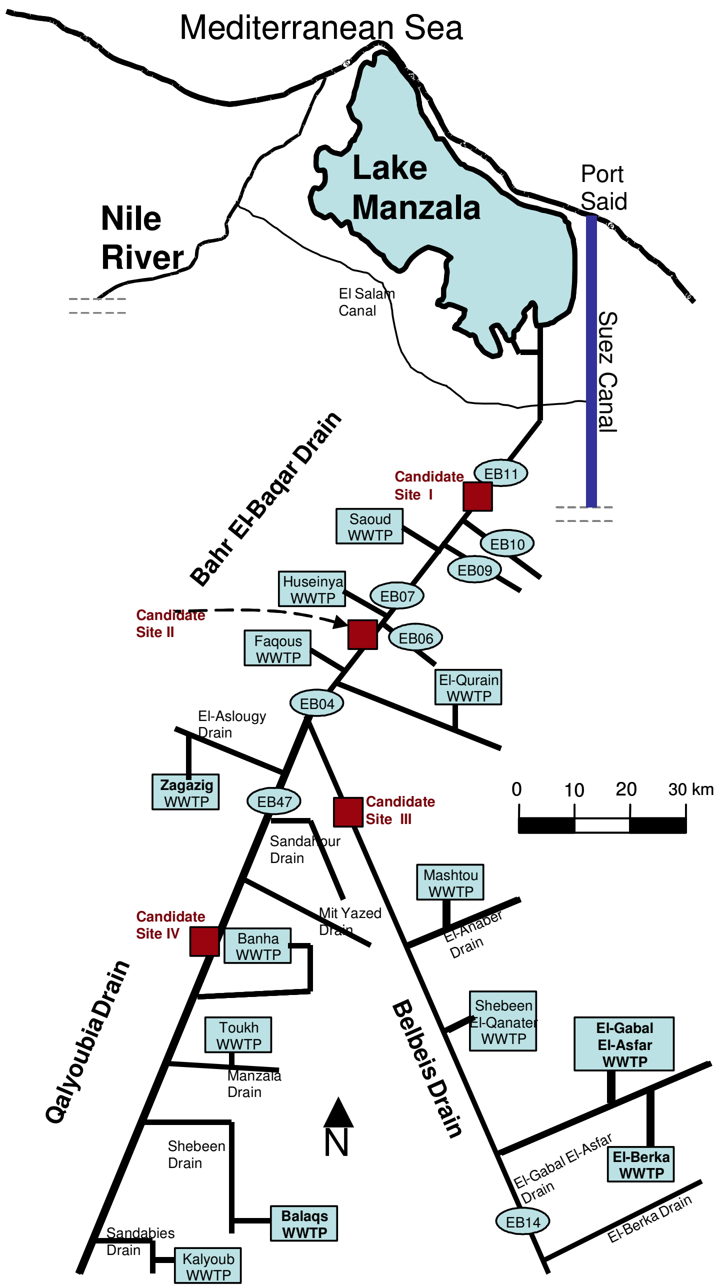

Fig. 3.5. Candidate Site Locations for the Fertilizer Plant

The reverse problem formulation was coded using software LINGO (please see Appendix B for more details). The target compositions for maximum allowable phosphorus discharge of the fertilizer plant were calculated for each location. Consequently, the treatment costs and total annualized costs of the land and interception were evaluated and used as the basis for comparing the four candidate sites. The results of the study are listed in Table 3.4.

TABLE 3.4
Results of Reverse Problem Formulation and Associated Economics

Location	Maximum Target for P in Effluent mg/L (Calculated through Reverse Problem Formulation)	Minimum P Load (kg/yr) to be Removed to Satisfy the Desired Target for Lake Manzala	Interception Cost $MM/yr	Total Annualized Cost $MM/yr
Site I	5.6	435384	9.14	19.14
Site II	10.21	144387	3.03	20.03
Site III	13.93	0	0	35
Site IV	18.73	0	0	18

For Sites I and II, which are closer to the discharge into Lake Manzala, the initial concentration of the plant effluent cannot be discharged directly into the reaches without violating the final watershed concentration. As a result, interception will need to be employed for these two sites. Sites III and IV, located on the Belbeis and Qalyoubia drains, respectively, do not require interception and could even have effluent concentrations that exceed the design. The optimal location for the fertilizer plant is Site IV.

From the results, it is possible to have a discharge of 18.73 mg/l for Site IV and still meet the watershed concentration of 1.3 mg/. Since the plant will not discharge more than the design concentration of 12.5 mg/l, the actual concentration of the final input to the lake will be 1.26 mg/l. As a result of the long residence time and the natural phosphorus removal mechanism in the reach, the effluent from Site IV will reduce the total P load to the lake.

III.5. CONCLUSIONS

A new approach has been introduced for integrating discharges of industrial processes with the larger watershed system to which they discharge. The concept of reverse problem formulation has been introduced to enable the identification of maximum allowable target compositions of pollutants in the process effluents that upon interaction with the rest of the watershed will meet the overall environmental requirements of the system. An optimization formulation has been developed to systematically implement the reverse problem concept. This approach overcomes the conventional limitation of the forward modeling approaches which require laborious trials to adjust the environmental performance of the process and to study its impact on the macroscopic environmental systems. A case study on managing phosphorus in Bahr El-Baqar has been solved. First, an MFA model was developed and verified via comparison with measurements. Next, the problem of locating a new fertilizer plant has been addressed. The reverse problem formulation has been used to determine target compositions for phosphorus corresponding to four candidate locations. Economic evaluations were used to select a site.

CHAPTER IV

DESIGN AND INTEGRATION OF ECO-INDUSTRIAL PARKS

IV.1. INTRODUCTION

An eco-industrial park "EIP" is a cluster of several processes that are not necessarily part of the same company or organization but share a common infrastructure that is designed and operated primarily to induce integration of materials exchange, waste treatment, and discharge. Participation of multiple facilities normally offers attractive economic and other advantages over the current stand-alone processing model. Because of the high level of interaction provided by the EIP, a systems integration approach must be adopted to design the common infrastructure and to make decisions on the optimal allocation of streams.

A key condition for an EIP to successfully attract industrial participants, it should demonstrate that the sum of the benefits achieved by working as collective is greater than working as a stand-alone facility. Indeed, collaborative efforts through EIP participation have resulted in benefits to industry, the surrounding community, the government and the environment. Through the efficient sharing/management of resources such as energy, water and materials, a business can effectively reduce costs associated with production (raw materials), waste disposal and utility usage. A by-product that was previously discharged as waste can now bring economic benefit through use as an input to another participant; furthermore, regulatory burdens previously associated with certain discharges can be reduced. For communities, EIPs improve the surrounding environment and bring new jobs and businesses to the area that leads to an improvement in the local economy. The governments receive an increase in tax revenue, a reduction on their municipal demands (e.g. water usage) along with reduced costs associated with environmental damages (Lowe, 1997).

There are several successful examples of EIPs. One of the most successful examples is Kalondborg Park, located in Finland. Although originally, the facility was not designed to serve as an EIP, it later evolved into a well-integrated system.

Participating companies include different industries such as an electric power plant, an oil refinery, a cement factory, a gypsum plasterboard factory, a pharmaceutical company, a fish nursery and the City of Kalondborg water and heating works. There are also good examples in the U.S. These include Brownsville EIP (Texas), Cabazon Resource Recovery Park (California), Devens Planned Community (Massachusetts), Fairfield Ecological Industrial Park, Baltimore (Maryland), Phillips Eco-Enterprise Center (Minnesota), and Port of Cape Charles Sustainable Technologies Industrial Park, Northampton County (Virginia). Examples of EIPs in Europe include Crewe Green Business Park (UK), Dyfi Eco-Park, Wales (UK), London Remade eco-industrial sites (UK), Ecopark Oulu (Finland), Emscher Park (Germany), Hartberg Okopark (Austria), Montagna-Energia Valle di Non (Italy), Sphere EcoIndustrie d'Alsace (France), and Vreten (Sweden). A good example from China is the Nanning Sugar Co., Ltd. consisting of 6 affiliated companies and 8 subsidiaries involved in sugar refining and paper-making, underwent an initiative to centralize its sugar-refining, pulping, pollution control and intensive operations which led to a reduction in energy, raw material usage, waste discharge and achieved a cleaner production system. Pollution emissions for COD, SO2 and water consumption were reduced by 62%, 59% and 35 %, respectively and net profits increased nearly 60-fold (Yang & Feng, 2008).

Not much research has been undertaken in the area of systematically locating, designing and operating EIPs. Fernandez et al. (2008) devised a model to determine the optimal location for a sustainable EIP. Traditionally, the proximity of resources, existence of infrastructure and availability of labor has been used to determine the location of an EIP. The model uses the analytic hierarchy process (AHP) to apply multicriteria evaluation in analyzing different areas that could be suitable locations. The model is divided into three levels (geographic area selection, evaluation and selection of suitable areas and evaluation of specific zones) which are grouped into categories and subcategories that are analyzed and prioritized according to the importance of goal variables (social, economic, environment, planning and infrastructure). Also considered are factors such as the availability and quality of natural resources, infrastructures and services. Weights are applied to the different factors in the model, leading to the identification of the suitable location. Sendra et al., (2007) adapted a material flow analysis tool to account for the flow of materials into and out of EIPs. Indicators such as direct material input, total material requirement, total water input, total water generated and total energy input were generated to quantify the material/energy usage of a company. By combining the indicators with other environmental tools, a strategy to convert an area into an EIP was obtained. Zhao et al., (2007) used system dynamics and grey cluster methods to simulate and evaluate a redesigned eco-industrial system in Changchun Economic and Technological Development Zone in China. Four different development strategies were studied: the do-nothing scenario, the focus on economic development scenario, the impact on the environment scenario, and the economic impact scenario (subject to interactions with science, technology and environmental advances).

Though good in theory, an EIP faces numerous challenges that can hinder its design and development. According to Spriggs et al., (2004), these challenges can be grouped into two classes: technical/economic challenge and organizational/commercial/political challenges and include the following issues:

a) The Technical/Economic Challenge: No EIP can be successful if the exchanges among the participating companies are unfeasible. Thus, there should be a connectivity among the companies within the EIP in which the streams (energy, byproducts, water, etc) can serve as inputs/outputs to one another. Another challenge lies in how to optimally and economically integrate the mass and energy flows in a system, either within the processing unit itself, between different processing areas or between different companies. The infrastructure may not exist between the companies and integration can be used to optimally allocate the mass and energy flows amongst the different participants.

b) The Organizational/Commercial/Political challenge: Though it would seem that the technical/economic challenges would pose the largest obstacle, it is actually the latter group that can present the biggest hurdle. Each business that comprises an EIP has its own set of rules and regulations and can impact the way information is disseminated within the EIP. Good communication, trust and cooperation amongst the participants are crucial to setting the stage for success. With all the different companies, ownership of certain issues becomes a challenge. For example, how will the EIP be managed? Who owns which production unit? What are the legal issues surrounding a by-product once it leaves a plant's battery limits and becomes feed to another? If a key player in the EIP should withdraw from the site, how will the remaining companies be affected? Small EIPs are vulnerable to market fluctuations and can fail due to the loss of a key anchor. What is the optimal level of integration that should be achieved between companies? Can new companies be brought into the mix and how will that affect the current integrated system? These are some of the challenges facing EIP's and require businesses to be flexible and adaptable to fluctuations that occur in an ever-changing business world.

This chapter is aimed at developing an optimization-based approach to the design and integration of eco-industrial parks (EIPs). Focus is given to the management of water among multiple processes in a common EIP facility. Recycle, reuse, and separation using interception devices are considered as possible strategies for managing wastewater. A source-interception-sink structural representation is used to embed potential configurations of interest. The representation accounts for the possibilities of direct recycle, material (waste) exchange, mixing and segregation of different streams, separation and treatment in interception units, and allocation to process users (sinks).

Then, the EIP design problem is formulated as an optimization program whose objective is to minimize cost of the EIP while determining optimal recycle and separation strategies. A case study is solved to illustrate the applicability of the devised approach.

IV.2. PROBLEM STATEMENT

Given a set PROCESSES = {p|p = 1,2, …, $N_{Process}$} of industrial processes. For each process, the following are given:

- A set of process sinks (units): $SINKS_p = \{j_p \mid j_p = 1,2, \ldots, N_{sinks,\ p}\}$. Each sink requires a certain flowrate, G_{j_p} and a given pollutant composition, $z_{j_p}^{in}$, which must satisfy the following constraint:

$$z_{j_p}^{\min} \le z_{j_p}^{in} \le z_{j_p}^{\max} \qquad \forall\, j_p \in \{1 \ldots N_{sinks,p}\} \tag{4.1}$$

where $z_{j_p}^{\min}$ and $z_{j_p}^{\max}$ are given lower and upper bounds on permissible compositions to unit j_p.

- A set of process effluent wastewater streams referred to as sources: SOURCES = $\{i_p \mid i_p = 1,2, \ldots, N_{sources,p}\}$. Each sources has a given flowrate, F_{i_p}, and a given pollutant composition, $y_{i_p}^{in}$.

It is desired to design an EIP that treats various sources from the $N_{processes}$ processes and assigns them to different sinks. The EIP will require the installation of a set of interception units: INTERCEPTORS = $\{k \mid k = 1,2, \ldots, N_{Int}\}$ to be used for treating the effluents by reducing the composition the targeted species to allow them to be assigned to various process sinks.

Available for service is a fresh (external) resource (fresh water) that can be purchased to supplement the use of process sources. Figure 4.1 is a schematic representation of the problem illustrating the various sources, interceptors within the EIP, sinks, and environmental discharges.

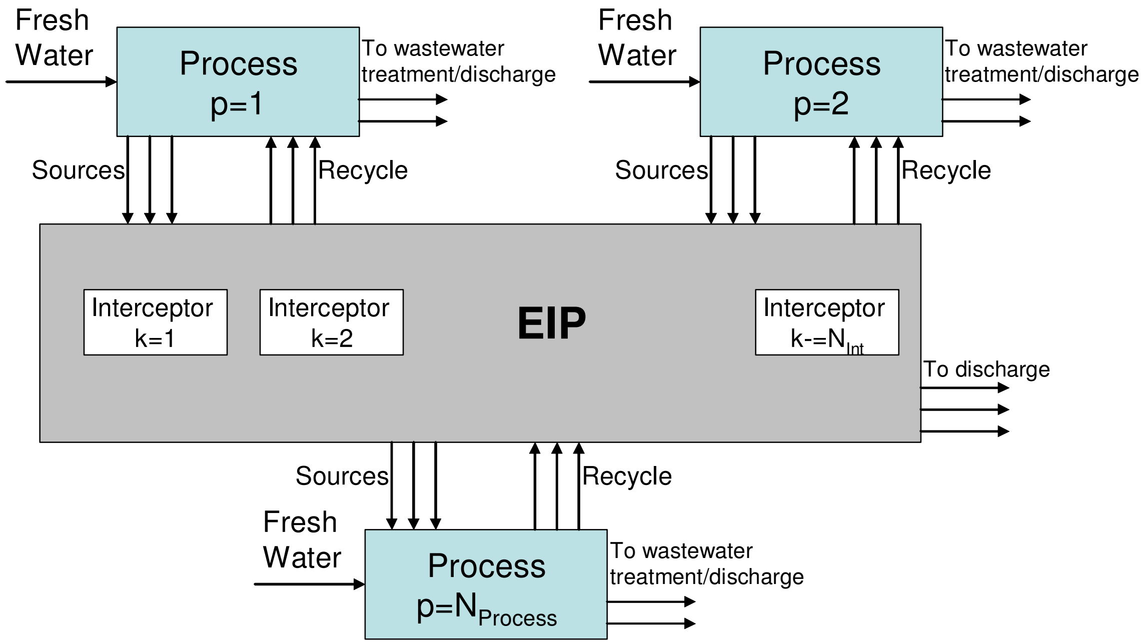

Fig. 4.1. Schematic Representation of the EIP Design Problem

It is desired to develop a systematic procedure that can be used to determine:

- The type, size, and number of the interception units constituting the EIP
- Which streams should be allocated to the EIP? To remove how much? Using which interception devices?
- How should the streams leaving the EIP be allocated?
- Which streams should be recycled to the same process?

IV.3. PROBLEM REPRESENTATION

In order to simplify the terminology, a single index, i, is given to all the sources. Therefore, $i_1 = 1$ is designated to be i =1, $i_1 = 2$ is designated to be i = 2, and so on until $i_1 = N_{Sources,1}$ which is referred to as i = $N_{Sources,1}$, then $i_2 = 1$ which is given the index i = $N_{Sources,1} + 1$, etc. Similarly, a single index, j, is given to all the sinks. Next, a source-interception-sink representation (Fig. 4.2.) is used to embed all potential configurations of interest (e.g. El-Halwagi, 2006; Gabriel & El-Halwagi, 2005). Each source is split into several fraction and assigned to interceptors within the EIP or to wastewater treatment facilities. Intercepted streams are allowed to mix and be assigned to different sinks within the multiple processes associated with the EIP. Unassigned streams are discharged as waste. It is worth noting that a stream may enter the EIP and go through "zero interception", i.e. it is not intercepted. In this case, the stream may mix with other streams and provide an inter-plant materials (waste) exchange strategy. The external fresh water stream can be used in process sinks to supplement the use of the process and treated streams.

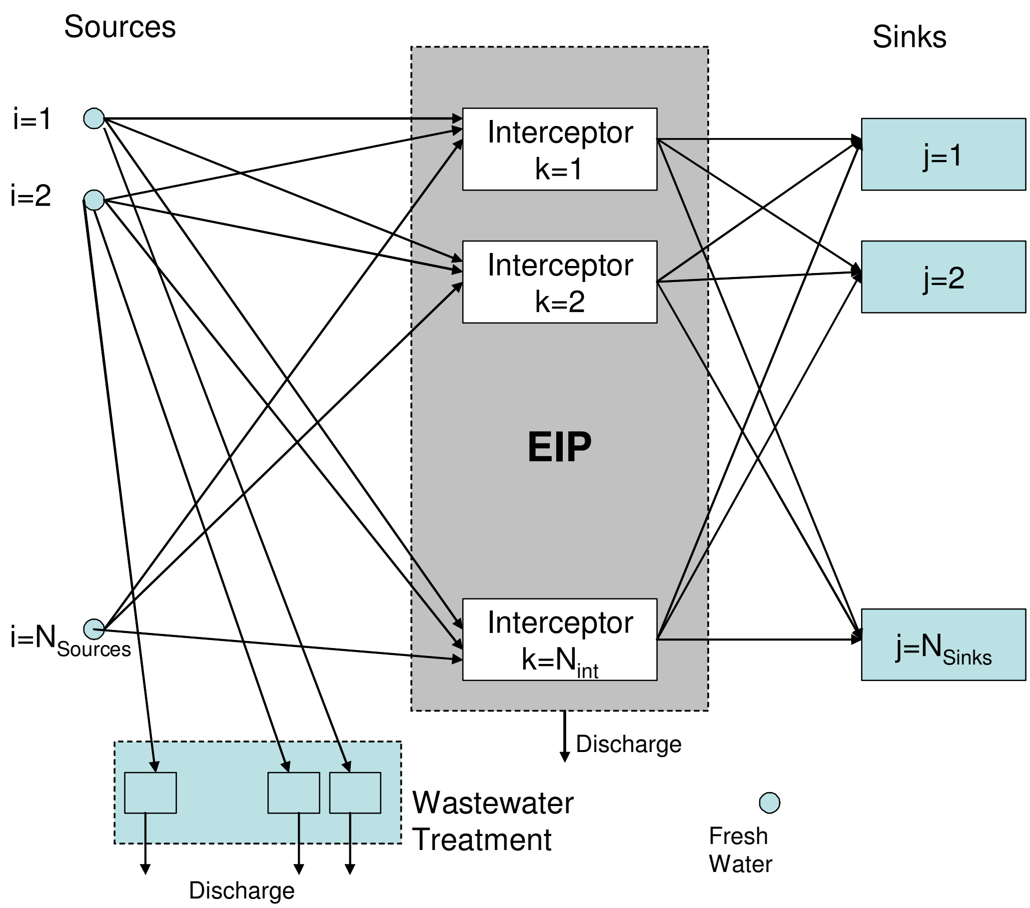

Figure 4.2. Structural Representation of the Problem

IV.4. OPTIMIZATION FORMULATION

The objective is to minimize the total annualized cost of the interception devices in the EIP, the cost of fresh water, and waste treatment. Therefore, the objective function is given by:

Minimize total annualized cost =

$$\sum_{k=1}^{N_{\mathrm{int}}} Interception\_Cost_k + C_{Fresh} \sum_{j=1}^{N_{\mathrm{sin}\,ks}} Fresh_j + C_{waste} \cdot waste \qquad (4.2)$$

where $Interception\_Cost_k$ is the total annualized cost associated with interception device k, C_{Fresh} is the cost of the fresh water ($/unit mass of water), $Fresh_j$ is the amount of fresh water fed to the j^th sink (mass per year), and C_{waste} is the annual waste treatment cost and *waste* is the total amount of flow going to waste (mass/yr).

Subject to the following constraints:

Distribution of effluent sources to interception devices and wastewater treatment:

$$F_i = \sum_{k=1}^{N_{\mathrm{int}}} w_{i,k} + w_i^{waste} \qquad \forall\, i \in \{1 \ldots N_{Sources}\} \qquad (4.3)$$

where F_i is the flowrate of the i^{th} source.

Material balance for the mixed sources before entering the k^{th} interceptor:

$$W_k = \sum_{i=1}^{N_{sources}} w_{i,k} \qquad \forall\, k \in \{1 \ldots N_{int}\} \qquad (4.4)$$

Component material balance for the mixed sources before entering the k^{th} interceptor:

$$W_k \cdot Y_k^{in} = \sum_{i=1}^{N_{sources}} w_{i,k} \cdot y_i^{in} \qquad \forall\, k \in \{1 \ldots N_{int}\} \qquad (4.5)$$

Design model for the k^{th} interceptor:

$$y_k^{out} = f_k(W_k, Y_k^{in}, D_k, P_k) \qquad \forall\, k \in \{1 \ldots N_{int}\} \qquad (4.6)$$

where D_k and P_k are the design and operating variables of the k^{th} interceptor.

Distribution of intercepted streams from the EIP to the process sinks:

$$W_k = \sum_{j=1}^{N_{\sin k}} g_{k,j} \qquad \forall\, k \in \{1 \ldots N_{int}\} \qquad (4.7)$$

Mixing of the distributed streams before the j[th] sink:

$$G_j = F_j + \sum_{k=1}^{N_{\text{int}}} g_{k,j} \qquad \forall\, j \in \{1 \ldots N_{sinks}\} \qquad (4.8)$$

Pollutant load and composition constraints for the feeds to the process sinks:

$$G_j \cdot z_j^{in} = F_j \cdot y_{fresh} + \sum_{k=1}^{N_{\text{int}}} g_{k,j} \cdot y_k^{out} \qquad \forall\, j \in \{1 \ldots N_{sinks}\} \qquad (4.9)$$

$$z_j^{\min} \le \mathrm{z}_\mathrm{j}^{\mathrm{in}} \le z_j^{\max} \qquad \forall\, j \in \{1 \ldots N_{sinks}\} \qquad (4.1)$$

The remaining unused material from the EIP is discharged:

$$EIP_{disch\arg e} = \sum_{k=1}^{N_{\text{int}}} g_{k,\, j=Waste} \qquad (4.10)$$

Finally, non-negativity constraints are added

$$g_{k,j} \ge 0 \qquad \forall\, k \in \{1 \ldots N_{int}\} \text{ and } \forall\, j \in \{1 \ldots N_{sinks}\} \qquad (4.11)$$

$$w_{i,k} \ge 0 \qquad \forall\, i \in \{1 \ldots N_{sources}\} \text{ and } \forall\, k \in \{1 \ldots N_{int}\} \qquad (4.12)$$

$$F_j \ge 0 \qquad \forall\, j \in \{1 \ldots N_{sinks}\} \qquad (4.13)$$

$$EIP_{disch\arg e} \ge 0 \qquad (4.14)$$

Depending on the interception modeling and cost functions, the above formulation is a nonlinear program (NLP) or mixed-integer nonlinear program (MINLP) which can be solved to determine the design of the EIP, the assignment of streams entering and leaving the EIP, and the distribution of the fresh usage and wastewater discharge.

IV.5. CASE STUDY

Consider an industrial complex with five plants as shown in Figure 4.3. It is desired to design an EIP to integrate five sources and four sinks. The data for the sources and the sinks are given in Tables 4.1 and 4.2. Five interceptions technologies are considered for potential incorporation into the EIP. The data for the interception technologies are given in Table 4.3. Fresh water may be used as needed at a cost of 0.6/ton. The EIP is to be operated for 8,760 hours per year.

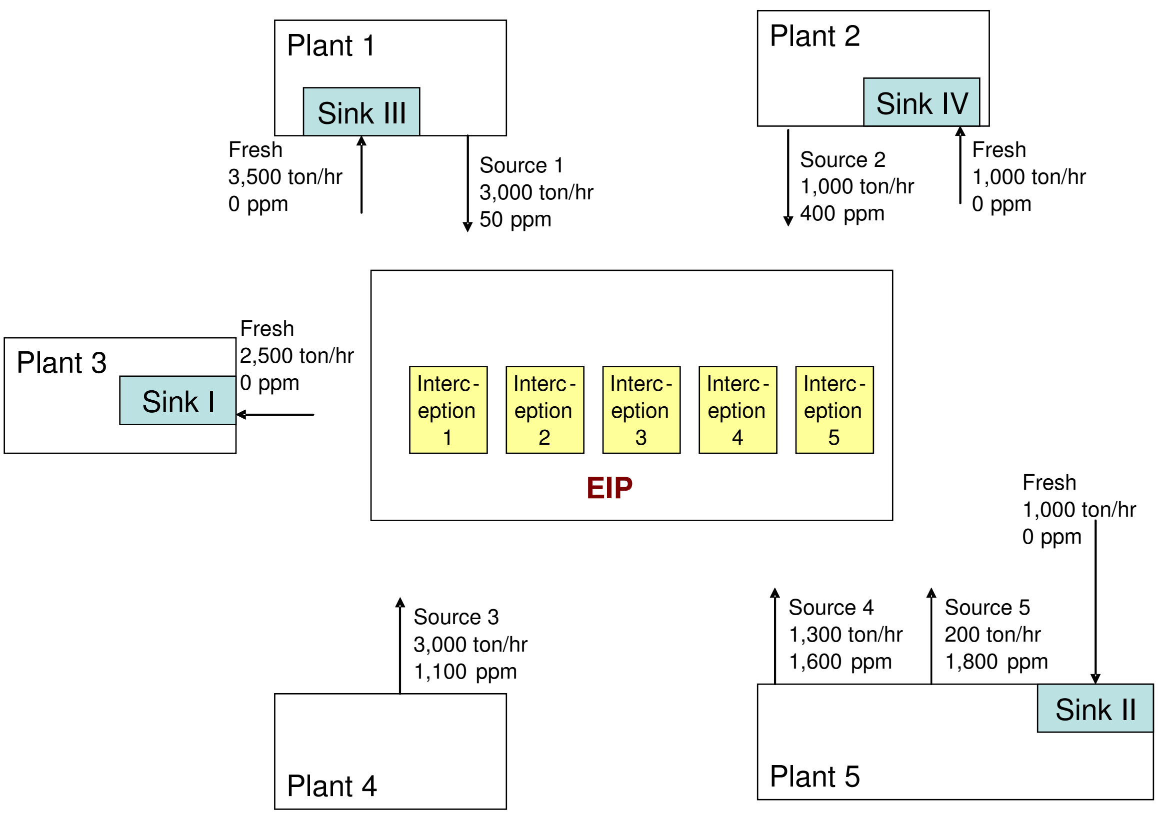

Fig. 4.3. Schematic Representation of the Case Study

TABLE 4.1 Sink Data for the EIP Case Study		
Sink	Flowrate ton/hr	Maximum Inlet Composition of Pollutant (ppm)
I	2,500	40
II	2,000	225
III	3,500	500
IV	1,000	760

TABLE 4.2 Source Data for the EIP Case Study		
Source	Flowrate ton/hr	Inlet Composition of Pollutant (ppm)
I	3,000	50
II	1,000	400
III	3,000	1100
IV	1,300	1600
V	200	1800

TABLE 4.3 **Interception Data for the EIP Case Study**			
Interception Technology	Minimum Inlet Composition of Intercepted Stream (ppm)	Minimum Outlet Composition of Intercepted Streams (ppm)	Interception Cost ($/kg removed)
I	1000	450	0.05
II	800	300	0.06
III	370	250	0.08
IV	300	100	0.09
V	280	30	0.16

Following the previously described optimization formulation, an NLP is formulated using the given data with the objective of minimizing the total annualized cost of the fresh and the interception devices. The Global Solver of the software LINGO (Schrage, 1999) was used to solve the problem (please see Appendix C for more details). The result is minimum-cost solution of $4,042,740/year. One interception technology is selected. Several material mixing and exchange strategies are also identified. The solution is represented in Fig. 4.4. It is worth noting that the original cost of the fresh before the EIP was $47,304,000/yr. Therefore the EIP has provided significant savings via integration and conservation of water resources.

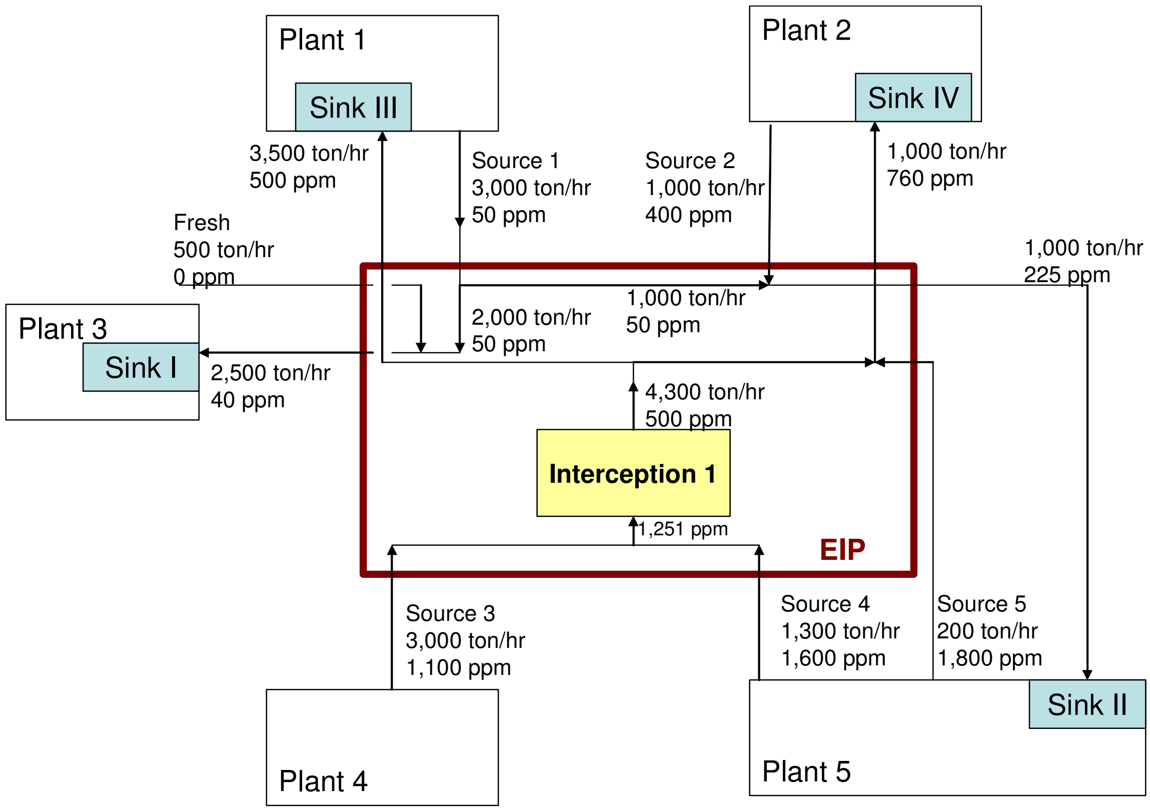

Fig. 4.4. Implementation of the Identified EIP Solution

IV.6. CONCLUSIONS

An optimization-based approach has been introduced for the systematic the design and integration of eco-industrial parks (EIPs). A source-interception-sink structural representation has been developed to include various structural configurations of interest including direct recycle/reuse, materials exchange, separation and treatment in interception units, and allocation to process users (sinks). An optimization formulation has been developed to represent the devised concept. A case study has been solved to show the power and effectiveness of the developed approach and optimization formulation.

CHAPTER V
OPTIMAL DESIGN AND SCREENING OF ALTERNATIVES FOR ADVANCED LIFE SUPPORT SYSTEMS

V.1. INTRODUCTION

Recently, the National Aeronautics and Space Administration (NASA) has embarked on an ambitious mission to develop operable prototypes for an Advanced Life Support System (ALS). The objective of the ALS is to avoid costly shuttle missions by devising planetary habitation systems that replicate the Earth's ecosystem. A critical element in sustaining planetary habitation is design and screening of alternatives for conserving material resources (e.g., waste management, recycle of materials, etc.) using proper metrics. Equivalent System Mass (ESM) is one of the metrics used by NASA to assess costs in ALS studies. The ESM calculations are particularly useful in comparing several alternative configurations in order to determine which of the viable options present the most attractive alternative for a given mission with a certain destination and duration. The analysis involves measuring the parameters of mass, volume, power, cooling and crew time and utilizing equivalency factors for volume, power, cooling, and crew time equivalency factors as described by the following expression (Levri et al., 2003; Hanford, 2003):

$$ESM = M + (V*V_{EQ}) + (P*P_{EQ}) + (C*C_{EQ}) + (CT*D*CT_{EQ}) \qquad (5.1)$$

Where

M = the total mass of the system [kg],

V = the total pressurized volume of system [m^3],

V_{eq} = the mass equivalency factor for the pressurized volume infrastructure [kg/m^3],

P = the total power requirement of the system [kWe] (kWe = kW electrical),

P_{eq} = the mass equivalency factor for the power generation infrastructure [kg/kWe],

C = the total cooling requirement of the system [kWth] (kWth = kW thermal),

C_{eq} = the mass equivalency factor for the cooling infrastructure [kg/kWth],

CT = the total crewtime requirement of the system [CM-h/y],

D= the duration of the mission segment of interest [y],

CTeq = the mass equivalency factor for the crewtime support [kg/CM-h].

The equivalency factors are determined by computing the ratio of the unit mass of infrastructure required per unit of resource. More information on the evaluation of equivalency factors and conducting EMS calculations can be found in Levri et al., 2003 and Hanford, 2003.

In many ALS applications, there are competing alternatives that can feasibly and reliably carry out the desired task with appropriate performance. In comparing alternatives, there are cases when the base design and some of its components are fixed. Therefore, in such cases it is not necessary to go through the full scale of ESM calculations which may be tedious. Instead, it is advantageous to focus the analysis on the components that make the difference among the alternatives.

It is instructive to recall a useful concept in the area of process economics which is commonly used in techno-economic feasibility studies for the chemical process industries. This concept is referred to as ***incremental return on investment "IROI"***. Suppose there are investment options to be added to a base design. Each additional dollar spent must provide sufficiently-large savings. Therefore, the IROI is defined as the ratio of the additional savings to the additional cost. This ratio must be greater than a certain attractive range in order for the proposed investment to be selected. The IROI concept is particularly useful in comparing alternatives. It can also inspire an analogous concept in the ESM-based comparison of alternatives for planetary habitation.

The purpose of this chapter is to introduce the new concept of incremental return on ESM and derive its basic expressions. In particular, we develop rigorous metrics that facilitate the comparison among alternatives. A case study on waste management will be used to demonstrate the applicability of the new concept.

V.2. DERIVATION OF INCREMENTAL RETURN ON ESM (IRESM)

As mentioned earlier, in comparing ALS alternatives there are cases when the base design and some of its components are fixed. Examples include one or more of the following categories:

- Adding, replacing, or removing a component to the system
- Changing an operating procedure
- System integration (e.g., mass or energy integration)

In such cases, it becomes tedious and unnecessary to carry out the full ESM calculations. Since many of the components of the base design are kept fixed, the emphasis should be on the unique changes that generate the alternatives.

Consider the ESM of the base design which consists of some terms that will remain constant and others that change. Therefore, the ESM for the base case can be expressed as:

$$ESM_{base} = \sum_{fixed\ terns} Fixed_{fixed\ terms} + \sum_{variable\ terms} Variable_{variable\ terms} \tag{5.2}$$

Now, consider an alternative i, for which some variables have increased and other variables have decreased compared to the base case. Consequently, the ESM for alternative i may be written as:

$$\begin{aligned} ESM_i = & \sum_{fixed\ terms} Fixed_{fixed\ terms} + \sum_{\substack{variable\ terms\ up \\ for\ alternative\ i}} Variable\_up\_for\_A_{\substack{variable\ terms\ up \\ for\ alternative\ i}} + \\ & \sum_{\substack{variable\ terms\ down \\ for\ alternative\ i}} Variable\_down\_for\_A_{\substack{variable\ terms\ down \\ for\ alternative\ i}} \end{aligned} \tag{5.3}$$

which can be rewritten as:

$$ESM_i = a + I_i + D_i \tag{5.4}$$

Where

$$a = \sum_{fixed\ terms} Fixed_{fixed\ terms} \tag{5.5}$$

$$I_i = \sum_{\substack{variable\ terms\ up \\ for\ alternative\ i}} Variable\_up\_for\_A_{\substack{variable\ terms\ up \\ for\ alternative\ i}} \tag{5.6}$$

which represents that terms of alternative i whose ESM will increase above the base case

$$D_i = \sum_{\substack{\text{variable terms down} \\ \text{for alternative } i}} Variable\_down\_for\_A_{\substack{\text{variable terms down} \\ \text{for alternative } i}} \tag{5.7}$$

which represents the terms of alternative i whose ESM will decrease below the base case

Therefore, the ESM for the base case can be rewritten as:

$$ESM_{base} = a + I_{base} + D_{base} \tag{5.8}$$

In order to compare the ESM for the base case and for alternative i, let us relate the terms I and D for both options by using the following expressions:

$$I_i = I_{base}(1+\alpha_i) \tag{5.9a}$$

i.e.,

$$\alpha_i = \frac{I_i}{I_{base}} - 1 \tag{5.9b}$$

which is a positive number indicating the extent of elevation in terms that increase from the base case to alternative i.

and

$$D_i = D_{base}(1-\beta_i) \tag{5.10}$$

i.e.,

$$\beta_i = 1 - \frac{D_i}{D_{base}} \tag{5.11}$$

which is a positive fraction indicating the extent of reduction in terms that decrease from the base case to alternative i.

Therefore,

$$EMS_i = a + I_{base}(1+\alpha_i) + D_{base}(1-\beta_i) \tag{5.12}$$

In order for alternative i to be superior to the base case, we have

$$ESM_i < ESM_{base} \tag{5.13}$$

By recalling Eqs. (5.4) and (5.8), we get

$$a + I_i + D_i < a + I_{base} + D_{base} \tag{5.14a}$$

Equivalently,

$$a + I_{base}(1+\alpha_i) + D_{base}(1-\beta_i) < a + I_{base} + D_{base} \tag{5.14.b}$$

i.e., for alternative I to be superior to the base case we must have:

$$\alpha_i * I_{base} < \beta_i * D_{base} \tag{5.14c}$$

We are now in a position to define the incremental return on ESM as:

$$IRESM_i = \frac{\beta_i * D_{base}}{\alpha_i * I_{base}} \tag{5.15}$$

In other words, IRESM for alternative i is the ratio of the reduction in ESM to the increase in ESM as a result of using alternative i instead of the base case. In this regard, it is analogous to IROI which relates savings to cost of competing investments. There are several useful observations:

- The mathematical condition for alternative i to be used in favor of the base case is:

  $$IRESM_i > 1 \tag{5.16}$$

  This means that alternative I will result in ESM savings more than the increase it will incur. Otherwise, if the IRESM of the alternative is less than one, it should not be used (unless there are non-ESM criteria for recommendation).
- The calculation of $IRESM_i$ does not involve the evaluation of the fixed terms in the base case (or alternative i). This save a significant portion of the calculation without compromising the validity of the results.
- The evaluation of the $IRESM_i$ depends on the *ratio* of the terms that decrease to those which increase and not the absolute values of those terms. As such, any consistent inaccuracies in evaluating those terms are canceled out. This provides higher accuracy than the conventional calculation of the ESM.

V.3. SCREENING MULTIPLE ALTERNATIVES

In some cases, more than one alternative may be considered to substitute the base design. If ESM is the key criterion for screening these alternatives, our objective is to select the alternative with the maximum net reduction in ESM compared to the base case. Consider a set P of promising alternatives (namely, the ones with IRESM greater than one), i.e.

$$P = \{i|i \text{ is an alternative, } IRESM_i > 1\} \quad (5.17)$$

Our objective is to find the optimum alternative ,i*, such that

$$ESM_{base\ case} - ESM_{i*} = \text{argmax } \{ESM_{base\ case} - ESM_i \mid i \in P\} \quad (5.18)$$

Equation (5.18) means that the optimum alternative is identified by comparing the difference between the ESM for the base case and the ESM for each alternative which is a member of the set P of promising alternatives, then selecting the member that gives the maximum net reduction in ESM from the base case. Recalling Eqs. (5.10) and (5.18), our objective is to find the alternative with the maximum value of

$$\begin{aligned} & a + I_{base} + D_{base} - [a + I_{base}(1+\alpha_i) + D_{base}(1-\beta_i)] = \\ & \beta_i * D_{base} - \alpha_i * I_{base} = \\ & \alpha_i * I_{base}(IRESM_i - 1) \end{aligned} \quad (5.19)$$

Therefore, Eq. (5.18) may be rephrased as: The optimum alternative i* is characterized by:

$$\text{argmax } \{ \alpha_i * I_{base}(IRESM_i - 1) \quad | i \in P\} \quad (5.20a)$$

In other words, the following ***screening rule*** can be used to select the optimum alternative:

From among the list of promising alternatives (i.e., the ones with $IRESM_i > 1$), the optimum alternative is the one with the following criterion:

$$\textit{Optimum alternative} \equiv \textit{maximum value of } \alpha_i * I_{base}(IRESM_i - 1) \quad (5.20b)$$

To illustrate the applicability of the IRESM concept, the following example is used.

V.4. CASE STUDY: OPTIMAL SCHEDULING OF WASTE MANAGEMENT SYSTEM

In planetary habitation, waste management is an important objective. One of the key wastes is biomass resulting from crop growth. An effective waste-management approach to crop growth waste is composting (Atkinson, 1997; Strayer & Atkinson, 1997). An attractive aspect of composting is its ability to release valuable nutrients that may be recovered and used in crop growth. An integrated experimental system was installed and operated at Tuskegee University's Center for Food & Environmental Systems for Human "CFESH" Exploration of Space. The system used an aerobic composting reactor (manufactured by Oxymax-C compost system from Columbus Instruments). Additional units involved air circulation, heating, cooling/condensation, organic recovery & nutrient leaching. A schematic diagram of the crop growth & waste management cycles along with the composting systems are shown in Figs. 5.1 & 5.2.

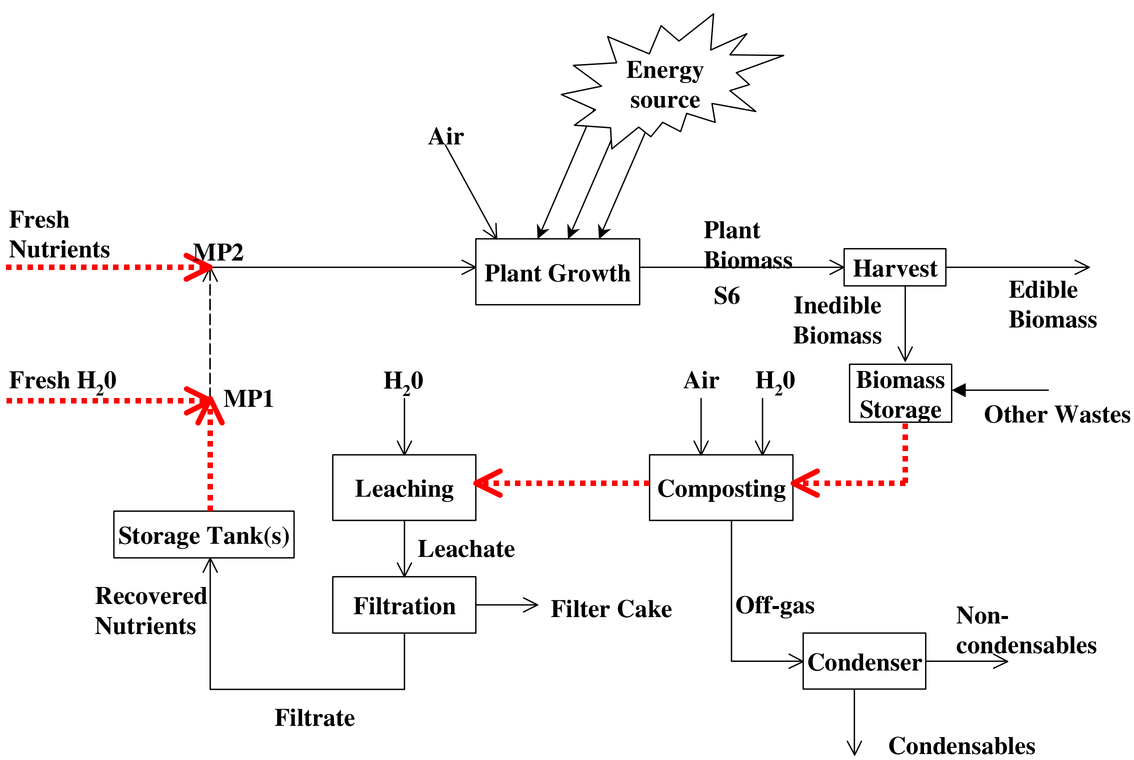

Fig. 5.1. Crop Growth, Waste Management, and Nutrient Recovery Cycle (El-Halwagi et al., 2003b)

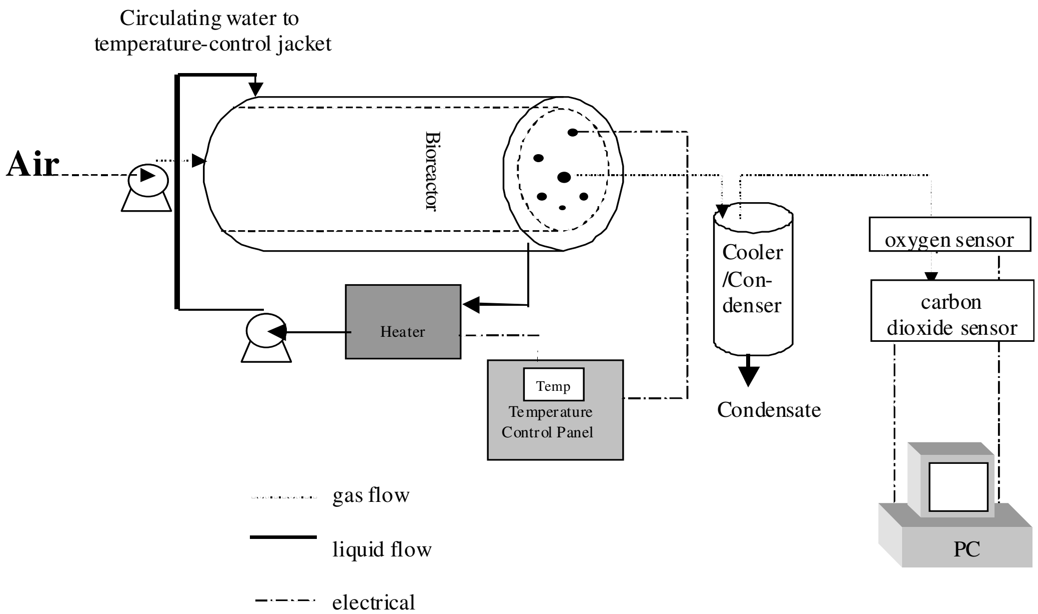

Fig. 5.2. A Schematic Representation of the Composting Setup
(El-Halwagi et al, 2003b)

El-Halwagi et al. (2003) investigated the nutrient recovery problem for the setup shown in Fig. 5.1. Using mass-integration strategies, they concluded that for the investigated conditions the optimum batch time should be about 20 days. Given that the typical crop growth period is about 120 days, there are several options for sizing the bio-reactor and scheduling the composting. The first option, is to size the bioreactor to handle the whole amount of bio-waste generated in 120 days (referred to as M_{Total}) in one batch that runs for 20 days. In this case, the bioreactor size is referred to as V_{Total} and the bioreactor will be idle for 100 days (assuming that there are no other wastes to be processed). Another option is to split the bio-waste into 6 batches (each of which is $M_{Total}/6$), size the reactor accordingly ($V_{Total}/6$) and run the batches in the same bioreactor consecutively. In general, one may split the bio-waste into n batches (each of which is M_{Total}/n), size the reactor accordingly (V_{Total}/n), and run the batches in the same bioreactor sequentially. As the number of batches increases, the mass and volume of the reactor decrease but the crew time increases for handling the various batches, cleaning, leaching, loading, unloading, maintenance, etc. Therefore, there is a tradeoff with respect to ESM. It is worth noting that regardless of the number of batches, the system will handle the same amount of bio-waste over 120 days, will use the same amount of water for leaching, will blow the same amount of air for composting, will provide the same total load of heating and cooling, etc. Therefore, instead of calculating the ESM for the whole system where most of its components will not change, it is much more effective to focus on the elements that will change. These are bioreactor weight, volume as well as crew time. Given the tradeoff of ESM as a function of the number of batches, our objective is to find the optimum number of batches and, consequently, the optimum bioreactor size that will minimize the ESM.

Let us select the alternative of splitting the bio-waste into six batches as the vase case (in a 120 crop growth cycle, with composting time of 20 days, the maximum number of batches is 6). As mentioned earlier, this base case corresponds to the least weight and volume of the reactor but involves the maximum crew time. There is no need to consider all the other ESM factors that will remain unchanged by varying the number of batches. Hence, we evaluate the ESM contributions for the element that will increase or decrease compared to the base case (i.e., crew time). The equivalence factors obtained from Hanford (2003) are assumed to be applicable to the alternatives under study. For the base case of six batches per cycle, we get:

D_{base} = 5,040 gm (which corresponds to the crew time) (5.21)

I_{base} = 2,380 gm (which corresponds to the weight and volume elements) (5.22)

Let n be the number of composting batches to be run in a 120-day crop growth cycle. Assuming a linear relationship between the number of batches and the crew time (e.g., in preparation of bio-waste and bacterial inoculum, batch loading, uploading, leaching, cleaning, etc.), we have

$D_i = 5{,}040*n/6 = 840*n$ (5.23)

Also, it is reasonable to assume that the reactor weight and enclosure volume are inversely proportional to the number of batches (because they are proportional to the weight of the bio-waste batch fed to the bioreactor for a given residence time). Therefore,

$$I_i = 2{,}380*6/n = 14{,}280/n \qquad (5.24)$$

Recalling Eqs. (8b) and (9b) and the expressions from Eqs. (5.13) - (5.16), we get

$$\alpha_i = \frac{6}{n} - 1 = \frac{6-n}{n} \qquad (5.25)$$

and

$$\beta_i = 1 - \frac{n}{6} = \frac{6-n}{6} \qquad (5.26)$$

Based on Eq. (14), we can now evaluate the IRESM for any alternative with n batches as:

$$IRESM_i = \frac{n*5{,}040}{6*2{,}380} = 0.35*n \qquad (5.27)$$

Since, $IRESM_i$ should be greater than one for the alternative to be competitive, therefore

$0.35*n > 1$

or

$$n > 2.8 \qquad (5.28)$$

Hence, for an alternative to be attractive compared to the base case, the number of batches should be 3 or more (in the studied case, this should be n = 3, 4, or 5).

Another relevant issue is the identification of the alternative with the maximum reduction in ESM. As mentioned by the screening rule of Eq. (5.20b), the metric $\alpha_i * I_{base}(IRESM_i - 1)$ is evaluated for the three alternatives to identify the maximum value.

$$\alpha_i * I_{base}(IRESM_i - 1) = \frac{6-n}{n} * 2{,}380 * (0.35 * n - 1) \tag{5.29}$$

By substituting the values of the three promising alternatives: n = 3, 4, 5, we get the values of the metric to be 119, 476, and 357 gm/cycle, respectively. Therefore, the optimum number of batches if four batches per a 120-day crop-growth cycle. The same result could have been obtained by using integer programming techniques to identify the integer n that maximizes the value of Eq. (5.29).

V.5. CONCLUSIONS

The chapter has introduced a computational metric to compare various alternatives in advanced life support and planetary habitation systems. The new metric is referred to as the incremental return on equivalent system mass (IRESM). It is based on two useful concepts: equivalent system mass (ESM) which is commonly used by NASA and incremental return on investment (IROI) which is commonly used by economists. The calculations for IRESM avoid un-necessary computations by focusing on the system elements that change. The chapter has also provided a selection criterion to identify the alternative which contributes to the maximum reduction of the total ESM of the system. A case study on optimal scheduling of crop-growth waste management has been solved to elucidate the applicability of the developed metrics.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This work has introduced systematic and generally applicable tools for the optimal design of four problems involving multiple scale and high levels of interaction. These four problems are: (1) environmental impact assessment of new and retrofitted industrial processes, (2) integration of process effluents with the macroscopic environmental systems, (3) eco-industrial parks, and (4) advanced life support systems for planetary habitation.

The following are the conclusions for each of these four problems. For the EIA Chapter, this work has presented an integrated approach to EIA which offers the following advantages:

- Assisting the engineer in quickly generating and screening project alternatives
- Excluding non-promising candidates from the analysis early enough
- Accounting for explicit and implicit environmental constraints
- Accounting for compounded environmental effects
- Inverting environmental constraints to the process and using process integration techniques to make appropriate process changes
- Reducing the process engineering efforts, gaining valuable insights early enough in the process, and systematizing the design effort while reconciling the various process objectives with the environmental objectives.

For the problem of integrating discharges of industrial processes with the larger watershed system to which they discharge, the concept of reverse problem formulation has been introduced to enable the identification of maximum allowable target compositions of pollutants in the process effluents that upon interaction with the rest of the watershed will meet the overall environmental requirements of the system. An optimization formulation has been developed to systematically implement the reverse problem concept. This approach overcomes the conventional limitation of the forward modeling approaches which require laborious trials to adjust the environmental performance of the process and to study its impact on the macroscopic environmental systems. A case study on managing phosphorus in Bahr El-Baqar has been solved. First, an MFA model was developed and verified via comparison with measurements. Next, the problem of locating a new fertilizer plant has been addressed. The reverse problem formulation has been used to determine target compositions for phosphorus corresponding to four candidate locations. Economic evaluations were used to select a site.

For the EIP problem, an optimization-based approach has been introduced for the systematic the design and integration of EIPs. A source-interception-sink structural representation has been developed to include various structural configurations of interest including direct recycle/reuse, materials exchange, separation and treatment in interception units, and allocation to process users (sinks). An optimization formulation has been developed to represent the devised concept. A case study has been solved to show the power and effectiveness of the developed approach and optimization formulation.

For the advanced life support systems, this work has introduced a computational metric to compare various alternatives in advanced life support and planetary habitation systems. The new metric is referred to as the incremental return on equivalent system mass (IRESM). It is based on two useful concepts: equivalent system mass (ESM) which is commonly used by NASA and incremental return on investment (IROI) which is commonly used by economists. The calculations for IRESM avoid un-necessary computations by focusing on the system elements that change. The chapter has also provided a selection criterion to identify the alternative which contributes to the maximum reduction of the total ESM of the system. A case study on optimal scheduling of crop-growth waste management has been solved to elucidate the applicability of the developed metrics.

The common conclusions for the four addressed problems and associated design procedures are:

a) Adopting an integrated framework enables proper reconciliation of different components and objectives of the common system.
b) The concept of targeting allows the designer to identify performance benchmarks ahead of detailed design and, therefore, provides a convenient method for treating multiple scales separately without losing the proper degrees of freedom for optimization
c) Optimization formulations in the form of nonlinear programs and mixed-integer nonlinear programs offer a powerful way for systematizing the developed concepts of targeting and design.

Recommendations for future work include:

1. Development of tailored global optimization procedures for the solution of the nonconvex formulations developed in this work.
2. Incorporation of process operation and scheduling concepts early enough in the conceptual design phase.
3. Instead of time-average MFA models for watersheds, it will be useful to develop dynamic models that constantly track variations in flows and compositions.
4. In addition to integrating EIPs based on composition (mass integration), it is desirable to integrate EIPs based on properties (property integration).
5. In addition to technical, economic, and environmental objectives, it is important to develop design procedures that include safety metrics for the four addressed problems.

NOMENCLATURE

C_{Fresh} = Fresh cost ($/tom)

C_{waster} = Waste cost ($/tom)

D_k = design variable of interceptor *k*

F_j= flow rate of the fresh to sink j (tons/hr)

$Fresh_j$ = amount of fresh resource fed to the sink *j* (tons/yr)

G_j = flowrate demand for sink *j* (tons/hr)

$g_{k,j}$ = amount of flow from interceptor *k to sink j* (tons/hr)

$Interception\_Cost_k$ = total annualized fixed equipment cost associated with interception device *k*

N_{sinks} = number of sinks

$N_{sources}$ = number of sources

N_{int} = number of interceptors

P_k = operating variable of interceptor *k*

y_k^{out} = outlet composition of interceptor *k* (ppm)

$w_{i,k}$ = amount of flow from source *i* to interceptor *k* (tons/hr)

W_k = total amount of flow going to interceptor *k* (tons/hr)

w_{i,k_i} = flow entering from source *i* to interceptor *k* (tons/hr)

waste = total amount of flow going to waste (tons/hr)

y_i^s = inlet (supply) composition of source *i* (ppm)

y_{fresh} = impurity composition in the fresh resource (ppm)

y_k^{in} = inlet composition of source *interceptors k* (ppm)

y_k^{out} = outlet composition of interceptor *k* (ppm)

$z_j^{\min}$ = lower bound composition to sink *j* (ppm)

$\mathrm{z}_\mathrm{j}^\mathrm{in}$ = inlet composition to sink *j* (ppm)

$z_j^{\max}$ = upper bound composition to sink j(ppm)

Indices

i = sources

j = sinks

k = interceptors

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APPENDIX A

AN EXAMPLE OF A LINGO FORMULATION FOR THE TARGETING OF EIA STUDIES

Application to the pulp and paper case study in Chapter II

CASE 1 1200 tpd pulp (chips = 4800 tpd)

```
Model:
MIN = FRESHTOTAL;
FRESHTOTAL = FRESH1 + FRESH2 + FRESH3 + FRESH4;
!MIN = C8 + C37;
C8_C37 = C8 + C37;
CProcess = C8 + C37 - C37BIO;
!Constraints on Recovery Furnace;

((K11+K16+K18)/39.1) - 0.1*((N11+N16+N18)/23) <=0.0;
(C11+C16+C18)/35 -0.02*((N11+N16+N18)/23) -0.02*((k11+K16+K18)/39)
<=0;
W33 = 20.66*PULP;
W37 = W33;
N371 - 0.0005*W371=0.0;
N372- 0.0005*W372 =0.0;
N373- 0.0005*W373 =0.0;
K371 - 0.000005*W371=0.0;
K372- 0.000005*W372 =0.0;
K373- 0.000005*W373 =0.0;
C371 - 0.0005*W371=0.0;
C372- 0.0005*W372 =0.0;
C373- 0.0005*W373 =0.0;
N37BIO - 0.0005*W37BIO =0.0;
K37BIO- 0.000005*W37BIO =0.0;
C37BIO- 0.0005*W37BIO =0.0;

FRESH4 + W124 + W104 - W33 = 0;

W37 - W371 - W372 - W373 - W37BIO= 0.0;
C37 - C371 - C372 - C373 - C37BIO = 0.0;
N37 - N371 - N372 - N373 - N37BIO = 0.0;
K37 - K371 - K372 - K373 - K37BIO = 0.0;

!Adding the bleach plant NPE content;

C33  - (3.7*10^-6)*W33 = 0.0;
K33 - (1.1*10^-6)*W33 = 0.0;
N33 -  (3.6*10^-6)*W33 = 0.0;

!RECYCLE;
FRESH1 =0;

!We'll fix recycle from screening to washers = 1450;
```

```
!but even if we don't, LINGO gives same answer;
!but instead of global solution, it will say local optimum;
W82 = 1450;

!sink 1 is screen, sink 2 is BS washer, sink 3 is washer/filter;
!BALANCES AROUND MIXING POINTS BEFORE SINKS;
W6 - W101 - W121 - W81 - W371- FRESH1 = 0;
W2 - W102 - W122 - W82 - W372- FRESH2 = 0;
W24 -  W83 - W103 - W123 -  W373- FRESH3 = 0;
!PURE CONDENSATE;
C81=0;
C121=0;
C101=0;
C122=0;
C102=0;
C123=0;
C103=0;
N81=0;
N121=0;
N101=0;
N122=0;
N102=0;
N123=0;
N103=0;
K81=0;
K121=0;
K101=0;
K122=0;
K102=0;
K123=0;
K103=0;
C6 - C101 - C121 - C81 - C371 - (3.7*10^-6)*FRESH1 = 0;
C2 - C102 - C122 - C82 - C372- (3.7*10^-6)*FRESH2 = 0;
C24 -  C83 - C103 - C123 - C373- (3.7*10^-6)*FRESH3 = 0;
K6 - K101 - K121 - K81 - K371 - (1.1*10^-6)*FRESH1 = 0;
K2 - K102 - K122 - K82 - K372- (1.1*10^-6)*FRESH2 = 0;
K24 -  K83 - K103 - K123 - K373 - (1.1*10^-6)*FRESH3 = 0;
N6 - N101 - N121 - N81 -N371 - (3.6*10^-6)*FRESH1 = 0;
N2 - N102 - N122 - N82 -N372- (3.6*10^-6)*FRESH2 = 0;
N24 -  N83 - N103 - N123 -N373 - (3.6*10^-6)*FRESH3 = 0;
!BALANCES AROUND SPLIT POINTS;
!NO SELF RECYCLE IN SCREEN;
W81=0;
W8 - W81 - W82 - W83 = 0;
W10 - W101 - W102 - w103 - W104 = 0;
W12 - W121 - W122 - W123 - W124  = 0;
C8 - C81 - C82 - C83 = 0.0;
K8 - K81 - K82 - K83 =0.0;
N8 - N81 - N82 - N83 =0.0;

!STREAMS 8-2 AND 8-3 HAVE SAME;
!COMPOSITION AS STREAM 8;
!C81 - W81*C8/W8  = 0.0;
```

```
!W8*K81 - W81*K8  = 0.0;
!W8*N81 - W81*N8  = 0.0;
W8*C82 - W82*C8  = 0.0;
W8*K82 - W82*K8  = 0.0;
W8*N82 - W82*N8  = 0.0;
W8*C83 - W83*C8  = 0.0;
W8*K83 - W83*K8  = 0.0;
W8*N83 - W83*N8  = 0.0;

! FRESH STREAMS "WET CHIPS";
CHIPS = 4800;
MOISTURE = 0.5;
W1 - 0.5*CHIPS = 0.0;
C1 - 1.0*CHIPS/6000 = 0.0;
K1  - 2.50*CHIPS/6000 = 0.0;
N1- 0.973*CHIPS/6000 = 0.0;
! CY IS CONSISTENCY = 0.12;
! YIELD = PULP/CHIPS ASSUME 50% OF DRY;
! CHIPS!WHICH IS (1- MOISTURE)*CHIPS ;
! è 0.5*0.5 = 0.25;
PULP - 0.25*CHIPS = 0.0;
!WASH WATER IS USED TO GIVE DILUTION FACTOR ;
! "DF" OF 2 è WASH WATER/ PULP = [(1-CY)/CY] + DF;
W2 - 9.33*PULP = 0.0;
! SPECIFY ION CONTENT OF PROCESS WATER 3.7, 1.1, ;
! AND 3.6 PPM  ;
!C2  - (3.7*10^-6)*W2 = 0.0;
!K2 - (1.1*10^-6)*W2 = 0.0;
!N2 -  (3.6*10^-6)*W2 = 0.0;
ME2 + MC2 <= 1.40;
!Screen Unit;
W6 = 1450;
!C6  - (3.7*10^-6)*W6 = 0.0;
!K6 - (1.1*10^-6)*W6 = 0.0;
!N6 -  (3.6*10^-6)*W6 = 0.0;
W7 - W4 = 0.0;
W8 - W6 = 0.0;
C7 - 0.8*C4 = 0.0;
K7 - 0.8*K4 = 0.0;
N7 - 0.8*N4 = 0.0;
C8 - C6 - C4 + C7 = 0.0;
K8 - K6 - K4 + K7 = 0.0;
N8 - N6 - N4 + N7 = 0.0;
ME6 + MC6 <= 1.40;
ME24 + MC24 <= 0.46;
ME10 = 1.8;
MC10 = 0.8;
ME12 = 0.15;
MC12 = 0.06;

! Digester/BROWN STOCK WAHSER;
W1 + W2 + W3 - W4 - W5 = 0;
C1 + C2 + C3 - C4 - C5 = 0;
```

```
K1 + K2 + K3 - K4 - K5 = 0;
N1 + N2 + N3 - N4 - N5 = 0;
! OUTLET PRODUCT FROM BROWN STOCK WASHER;
! HAS 12% CONSISTENCY  è WATER IN EFFLURNT =  ;
! [(1-CY)/CY]*PULP = 0.88/0.12*PULP = 7.33*PULP;
W4 - 7.33*PULP = 0.0;
! ASSUME RATIOS TO NOMINAL BALANCE;
C4 - 0.05*C5 = 0.0;
K4 - 0.02*K5 = 0.0;
! SODIUM IN EFFLUENT FROM WASHER IS 0.01 ;
!TONS (EXPRESSED AS NA2SO4) PER TON OF PULP;
! I.E. 0.01*46/142 LBS NA (EXPRESSED AS LBS NA) =;
! 0.003 TON NA/TON OF PULP;
!N4 - 0.003*PULP = 0.0;
N4 - 0.009*N5=0.0;
! EVAPORATORS ASSUME 80% WATER EVAPORATED;
! ASSUME NO IONS IN CONDENSATE;
W10 - 0.8*W5 = 0.0;
C10 = 0.0;
K10 = 0.0;
N10 = 0.0;
W5 - W9 - W10 = 0.0;
C5 - C9 - C10 = 0.0;
K5 - K9 - K10 = 0.0;
N5 - N9 - N10 = 0.0;
! CONCENTRATOR ASSUME 46% WATER EVAPORATED;
! ASSUME NO IONS IN CONDENSATE;
W12 - 0.46*W9 = 0.0;
C12 = 0.0;
K12 = 0.0;
N12 = 0.0;
W9 - W11 - W12 = 0.0;
C9 - C11 - C12 = 0.0;
K9 - K11 - K12 = 0.0;
N9 - N11 - N12= 0.0;
! RECOVERY FURNACE AND ESP;
W15 - W11= 0.0;
C15 - 0.02*C11 = 0.0;
K15 - 0.008*K11 = 0.0;
N15 - 0.0008*N11 = 0.0;
W14 = 0.0;
C14 - 0.048*C11 = 0.0;
K14 - 0.028*K11 = 0.0;
N14 - 0.002*N11 = 0.0;
! ASSUME SALT CAKE HAS MAKEUP FLOW OF; !0.0375*PULP FLOW;
SALTCAKE - 0.0375*PULP = 0.0;
! SALT CAKE IS NA2SO4 è AS NA = 46/142*SALTCAKE;
! = 0.324*SALT CAKE;
N18 - 0.324*SALTCAKE = 0.0;
!OVERALL BALANCES;
!N18+N2+N6+N1+N24-N8-N7-N14-N15-N23-N26-N28-N29+NERROR =0.0;
!W18+W2+W6+W1+W24-W8-W10-W12-W7-W14-W15-W23-W26-W28-W29- WaterSLK-
WERROR =0.0;
```

```
!K18+K2+K6+K1+K24-K8-K10-K12-K7- K14-K15-K23-K26-K28-K29-KERROR =0.0;
!C18+C2+C6+C1+C24-C8-C10-C12-C7-C14-C15-C23-C26-C28-C29-CERROR =0.0;
!n18 - 18=0.0;
! ASSUME CONTENT OF CL AND K IN SALTCAKE;
C18 - 0.01*N18 = 0.0;
K18 - 0.0014*N18 = 0.0;
! ALSO NO WATER IN SCAKE;
W18 = 0.0;
W17 = 0.0;
C11 + C18  - C15 - C14 - C17 = 0.0;
K11 + K18  - K15 - K14 - K17 = 0.0;
N11 + N18  - N15 - N14 - N17 = 0.0;
! BETWEEN FURNACE AND ESP, USE GLEADOWS PAPER;
W13 - W11 = 0.0;
K13 - 0.278*K11 = 0.0;
C13 - 0.498*C11 = 0.0;
N13 -  0.154*N11 = 0.0;
W13 - W14 - W15 - W16 = 0.0;
C13 - C14 - C15 - C16 = 0.0;
K13 - K14 - K15 - K16 = 0.0;
N13 - N14 - N15 - N16 = 0.0;
!SOLIDS IN STRONG BLACK LIQUOR SBL IS;
!65% OF STREAM è SOLIDSBL = 65/35*W11 OR;
! 1.86*W11;
SSBL - 1.86*W11 = 0.0;
!SOLIDS IN ESP EFFLUENT AND PURGE IS SMALL;
! ASSUME 5% OF SSBL;
!ASSUME 47% OF SOLIDS IN SBL ARE VOLATILIZED;
! IN FURNACE;
SALTCAKE + 0.53*SSBL - SMELT - 0.05*SSBL = 0.0;
!ASSUME DISSOLVING WATER IS 85:15 OF SMELT;
! = 5.67*SMELT;
W19 - 5.67*SMELT = 0.0;
!ASSUME CONENT OF Cl, K, AND Na;
! IN DISSOLVING LIQUID AS RATIOS TO SMELT;
!THIS IS A THREE-UNIT LOOP, INSENSISTIVE;
C19 - 0.136*C17 = 0.0;
K19 - 0.136*K17 = 0.0;
!FROM HOUGH P. 243;
N19 - 0.196*N3 = 0.0;
W20 - W17 - W19 = 0.0;
C20 - C17 - C19 = 0.0;
K20 - K17 - K19 = 0.0;
N20 - N17 - N19 = 0.0;
! ASSUME  RATIOS OF OVERFLOW TO FEED IN; !CLARIFIER BASED ON NOMINAL
BALANCES;
W21 - 0.992*W20 = 0.0;
C21 - 0.863*C20 = 0.0;
K21 - 0.880*K20 = 0.0;
N21 - 0.968*N20 = 0.0;
W22 + W21 - W20 = 0.0;
C22 + C21 - C20 = 0.0;
K22 + K21 - K20 = 0.0;
```

```
N22 + N21 - N20 = 0.0;
! WASHER/FILTER BALANCES;
!FOR DREGS, USE LITERATURE RATIOS TO UNDERFLOW;
!OF CLARIFIER;
! FROM  HOUGH, P. 243;
W23 - 0.075*W22 = 0.0;

!In dregs sodium : water = 1:16;
4*N23 - W23 = 0.0;
100*C23 - W23 = 0.0;
! FROM VIRKOLA;
1000*K23 - W23 = 0.0;
!RELATE WHITE LIQUOR CLARIFIER TO GREEN LIQUOR; !OVERFLOW BY RATIOS
FROM  HOUGH, P. 243;
W32 -  0.160*W21 = 0.0;
C32 -  0.237*C21 = 0.0;
K32 -  0.016*K21 = 0.0;
N32 -  0.156*N21 = 0.0;
! PROCESS WATER FOR WASHER FILTER;
!IS TAKEN AS RATIO TO SMELT-DISSOLUTION WATER;
W24 - 0.9*W19 = 0.0;
! SPECIFY ION CONTENT OF PROCESS WATER 3.7, 1.1, ;
! AND 3.6 PPM  ;
!C24  - (3.7*10^-6)*W24 = 0.0;
!K24 - (1.1*10^-6)*W24 = 0.0;
!N24 -  (3.6*10^-6)*W24 = 0.0;

! BALANCES AROUND WASHERS/FILTERS;
W22 + W24 + W32 - W19 - W23 - W25 = 0.0;
C22 + C24 + C32 - C19 - C23 - C25 = 0.0;
K22 + K24 + K32 - K19 - K23 - K25 = 0.0;
N22 + N24 + N32 - N19 - N23 - N25 = 0.0;
! LIME KILN;
!N26 - 0.0023*W26 = 0.0;
K26 - 0.0001*W26 = 0.0;
C26 - 0.0001*W26 = 0.0;
N27 - 0.05*N25=0.0;
! NO WATER IN LIME;
W27 = 0.0;
W25 - W26 - W27 = 0.0;
C25 - C26 - C27 = 0.0;
K25 - K26 - K27 = 0.0;
N25 - N26 - N27 = 0.0;
! WATER VAPORIZED IN SLAKER IS PURE AND .5% OF; !FEED WATER;
W29 - 0.005*W21 = 0.0;
C29 = 0.0;
K29 = 0.0;
N29 = 0.0;
! GRITS ASSUMPTIONS FROM HOUGH;
W28 - 0.0013*W21 = 0.0;
C28 - 0.0015*C21 = 0.00;
! FROM VIRKOLA;
K28 - 0.0053*K21 = 0.0;
```

```
N28 - 0.001*N21 = 0.0;
! ACCOUNT FOR WATER CONSUMPTION IN SLAKING;
! CaO + H20 = Ca(OH)2;
! è 18: 56  WATER: LIME è 0.32 WATER: LIME;
! FROM BIERMANN, P. 117, 0.35 TON LIME: TON PULP;
LIME - 0.35*PULP = 0.0;
! DEFINE WATERSLK AS WATER CONSUMED IN;
! SLAKING RXN;
WATERSLK - 0.32*LIME = 0.0;
W21 + W27 - W28 - W29 - W30 - WATERSLK = 0.0;
C21 + C27 - C28 - C29 - C30 = 0.0;
K21 + K27 - K28 - K29 - K30 = 0.0;
N21 + N27 - N28 - N29 - N30 = 0.0;
! OUT OF CAUSTIZER SAME AS IN TO CAUSTICIZER;
W31 - W30 = 0.0;
C31 - C30 = 0.0;
K31 - K30 = 0.0;
N31 - N30 = 0.0;
W31 - W32 - W3 = 0.0;
C31 - C32 - C3 = 0.0;
K31 - K32 - K3 = 0.0;
N31 - N32 - N3 = 0.0;

END
```

```
Global optimal solution found.
Objective value:                              32098.49
Total solver iterations:                             6
```

Variable	Value	Reduced Cost
FRESHTOTAL	32098.49	0.000000
FRESH1	0.000000	0.000000
FRESH2	7306.487	0.000000
FRESH3	0.000000	0.5344055E-03
FRESH4	24792.00	0.000000
C8_C37	12.50458	0.000000
C8	0.1085775	0.000000
C37	12.39600	0.000000
CPROCESS	0.3880708	0.000000
C37BIO	12.11651	0.000000
K11	34.92004	0.000000
K16	8.450650	0.000000
K18	0.2041200E-01	0.000000
N11	412.4220	0.000000
N16	62.35821	0.000000
N18	14.58000	0.000000
C11	10.85775	0.000000
C16	4.668834	0.000000
C18	0.1458000	0.000000
W33	24792.00	0.000000
PULP	1200.000	0.000000

W37	24792.00	0.000000
N371	0.000000	0.000000
W371	0.000000	0.000000
N372	0.2794933	0.000000
W372	558.9866	0.000000
N373	0.000000	0.000000
W373	0.000000	0.7422298E-01
K371	0.000000	0.000000
K372	0.2794933E-02	0.000000
K373	0.000000	0.000000
C371	0.000000	0.000000
C372	0.2794933	0.000000
C373	0.000000	0.000000
N37BIO	12.11651	0.000000
W37BIO	24233.01	0.000000
K37BIO	0.1211651	0.000000
W124	0.000000	0.7401577E-02
W104	0.000000	0.7401577E-02
N37	12.39600	0.000000
K37	0.1239600	0.000000
C33	0.9173040E-01	0.000000
K33	0.2727120E-01	0.000000
N33	0.8925120E-01	0.000000
W82	1450.000	0.000000
W6	1450.000	0.000000
W101	1450.000	0.000000
W121	0.000000	0.000000
W81	0.000000	0.000000
W2	11196.00	0.000000
W102	1061.600	0.000000
W122	818.9261	0.000000
W24	4609.497	0.000000
W83	0.000000	0.000000
W103	4609.497	0.000000
W123	0.000000	0.000000
C81	0.000000	0.000000
C121	0.000000	0.000000
C101	0.000000	0.000000
C122	0.000000	0.000000
C102	0.000000	0.000000
C123	0.000000	0.000000
C103	0.000000	0.000000
N81	0.000000	0.000000
N121	0.000000	0.000000
N101	0.000000	0.000000
N122	0.000000	0.000000
N102	0.000000	0.000000
N123	0.000000	0.000000
N103	0.000000	0.000000
K81	0.000000	0.000000
K121	0.000000	0.000000
K101	0.000000	0.000000
K122	0.000000	0.000000

K102	0.000000	0.000000
K123	0.000000	0.000000
K103	0.000000	0.000000
C6	0.000000	0.000000
C2	0.4151048	0.000000
C82	0.1085775	0.000000
C24	0.000000	0.000000
C83	0.000000	0.000000
K6	0.000000	0.000000
K2	0.1505122	0.000000
K82	0.1396802	0.000000
K24	0.000000	0.000000
K83	0.000000	0.000000
N6	0.000000	0.000000
N2	1.048156	0.000000
N82	0.7423596	0.000000
N24	0.000000	0.000000
N83	0.000000	0.000000
W8	1450.000	0.000000
W10	7121.097	0.000000
W12	818.9261	0.000000
K8	0.1396802	0.000000
N8	0.7423596	0.000000
CHIPS	4800.000	0.000000
MOISTURE	0.5000000	0.000000
W1	2400.000	0.000000
C1	0.8000000	0.000000
K1	2.000000	0.000000
N1	0.7784000	0.000000
ME2	0.000000	0.000000
MC2	0.000000	0.000000
W7	8796.000	0.000000
W4	8796.000	0.000000
C7	0.4343101	0.000000
C4	0.5428877	0.000000
K7	0.5587206	0.000000
K4	0.6984008	0.000000
N7	2.969439	0.000000
N4	3.711798	0.000000
ME6	0.000000	0.000000
MC6	0.000000	0.000000
ME24	0.000000	0.000000
MC24	0.000000	0.000000
ME10	1.800000	0.000000
MC10	0.8000000	0.000000
ME12	0.1500000	0.000000
MC12	0.6000000E-01	0.000000
W3	4101.371	0.000000
W5	8901.371	0.000000
C3	10.18554	0.000000
C5	10.85775	0.000000
K3	33.46793	0.000000
K5	34.92004	0.000000

N3	414.3073	0.000000
N5	412.4220	0.000000
C10	0.000000	0.000000
K10	0.000000	0.000000
N10	0.000000	0.000000
W9	1780.274	0.000000
C9	10.85775	0.000000
K9	34.92004	0.000000
N9	412.4220	0.000000
C12	0.000000	0.000000
K12	0.000000	0.000000
N12	0.000000	0.000000
W11	961.3481	0.000000
W15	961.3481	0.000000
C15	0.2171551	0.000000
K15	0.2793603	0.000000
N15	0.3299376	0.000000
W14	0.000000	0.000000
C14	0.5211722	0.000000
K14	0.9777611	0.000000
N14	0.8248440	0.000000
SALTCAKE	45.00000	0.000000
W18	0.000000	0.000000
W17	0.000000	0.000000
C17	10.26523	0.000000
K17	33.68333	0.000000
N17	425.8472	0.000000
W13	961.3481	0.000000
K13	9.707771	0.000000
C13	5.407161	0.000000
N13	63.51299	0.000000
W16	0.000000	0.000000
SSBL	1788.107	0.000000
SMELT	903.2916	0.000000
W19	5121.663	0.000000
C19	1.396071	0.000000
K19	4.580933	0.000000
N19	81.20422	0.000000
W20	5121.663	0.000000
C20	11.66130	0.000000
K20	38.26426	0.000000
N20	507.0515	0.000000
W21	5080.690	0.000000
C21	10.06370	0.000000
K21	33.67255	0.000000
N21	490.8258	0.000000
W22	40.97331	0.000000
C22	1.597598	0.000000
K22	4.591712	0.000000
N22	16.22565	0.000000
W23	3.072998	0.000000
N23	0.7682495	0.000000
C23	0.3072998E-01	0.000000

K23	0.3072998E-02	0.000000
W32	812.9104	0.000000
C32	2.385097	0.000000
K32	0.5387608	0.000000
N32	76.56883	0.000000
W25	338.6444	0.000000
C25	2.555894	0.000000
K25	0.5464665	0.000000
N25	10.82200	0.000000
K26	0.3386444E-01	0.000000
W26	338.6444	0.000000
C26	0.3386444E-01	0.000000
N27	0.5411001	0.000000
W27	0.000000	0.000000
C27	2.522029	0.000000
K27	0.5126021	0.000000
N26	10.28090	0.000000
W29	25.40345	0.000000
C29	0.000000	0.000000
K29	0.000000	0.000000
N29	0.000000	0.000000
W28	6.604897	0.000000
C28	0.1509555E-01	0.000000
K28	0.1784645	0.000000
N28	0.4908258	0.000000
LIME	420.0000	0.000000
WATERSLK	134.4000	0.000000
W30	4914.282	0.000000
C30	12.57063	0.000000
K30	34.00669	0.000000
N30	490.8761	0.000000
W31	4914.282	0.000000
C31	12.57063	0.000000
K31	34.00669	0.000000
N31	490.8761	0.000000

CASE 2 – 1500 tpd pulp, model is same the 1200 tpd formulation except CHIPS = 6000 tpd,

```
Global optimal solution found.
Objective value:                              40123.11
Total solver iterations:                             6
```

Variable	Value	Reduced Cost
FRESHTOTAL	40123.11	0.000000
FRESH1	0.000000	0.000000
FRESH2	9133.109	0.000000
FRESH3	0.000000	0.5344055E-03
FRESH4	30990.00	0.000000
C8_C37	15.63072	0.000000

C8	0.1357219	0.000000
C37	15.49500	0.000000
CPROCESS	0.4850885	0.000000
C37BIO	15.14563	0.000000
K11	43.65005	0.000000
K16	10.56331	0.000000
K18	0.2551500E-01	0.000000
N11	515.5275	0.000000
N16	77.94776	0.000000
N18	18.22500	0.000000
C11	13.57219	0.000000
C16	5.836042	0.000000
C18	0.1822500	0.000000
W33	30990.00	0.000000
PULP	1500.000	0.000000
W37	30990.00	0.000000
N371	0.000000	0.000000
W371	0.000000	0.000000
N372	0.3493666	0.000000
W372	698.7333	0.000000
N373	0.000000	0.000000
W373	0.000000	0.7422298E-01
K371	0.000000	0.000000
K372	0.3493666E-02	0.000000
K373	0.000000	0.000000
C371	0.000000	0.000000
C372	0.3493666	0.000000
C373	0.000000	0.000000
N37BIO	15.14563	0.000000
W37BIO	30291.27	0.000000
K37BIO	0.1514563	0.000000
W124	0.000000	0.7401577E-02
W104	0.000000	0.7401577E-02
N37	15.49500	0.000000
K37	0.1549500	0.000000
C33	0.1146630	0.000000
K33	0.3408900E-01	0.000000
N33	0.1115640	0.000000
W82	1450.000	0.000000
W6	1450.000	0.000000
W101	1450.000	0.000000
W121	0.000000	0.000000
W81	0.000000	0.000000
W2	13995.00	0.000000
W102	1689.500	0.000000
W122	1023.658	0.000000
W24	5761.871	0.000000
W83	0.000000	0.000000
W103	5761.871	0.000000
W123	0.000000	0.000000
C81	0.000000	0.000000
C121	0.000000	0.000000
C101	0.000000	0.000000

C122	0.000000	0.000000
C102	0.000000	0.000000
C123	0.000000	0.000000
C103	0.000000	0.000000
N81	0.000000	0.000000
N121	0.000000	0.000000
N101	0.000000	0.000000
N122	0.000000	0.000000
N102	0.000000	0.000000
N123	0.000000	0.000000
N103	0.000000	0.000000
K81	0.000000	0.000000
K121	0.000000	0.000000
K101	0.000000	0.000000
K122	0.000000	0.000000
K102	0.000000	0.000000
K123	0.000000	0.000000
K103	0.000000	0.000000
C6	0.000000	0.000000
C2	0.5188810	0.000000
C82	0.1357219	0.000000
C24	0.000000	0.000000
C83	0.000000	0.000000
K6	0.000000	0.000000
K2	0.1881403	0.000000
K82	0.1746002	0.000000
K24	0.000000	0.000000
K83	0.000000	0.000000
N6	0.000000	0.000000
N2	1.310195	0.000000
N82	0.9279496	0.000000
N24	0.000000	0.000000
N83	0.000000	0.000000
W8	1450.000	0.000000
W10	8901.371	0.000000
W12	1023.658	0.000000
K8	0.1746002	0.000000
N8	0.9279496	0.000000
CHIPS	6000.000	0.000000
MOISTURE	0.5000000	0.000000
W1	3000.000	0.000000
C1	1.000000	0.000000
K1	2.500000	0.000000
N1	0.9730000	0.000000
ME2	0.000000	0.000000
MC2	0.000000	0.000000
W7	10995.00	0.000000
W4	10995.00	0.000000
C7	0.5428877	0.000000
C4	0.6786096	0.000000
K7	0.6984008	0.000000
K4	0.8730010	0.000000
N7	3.711798	0.000000

N4	4.639748	0.000000
ME6	0.000000	0.000000
MC6	0.000000	0.000000
ME24	0.000000	0.000000
MC24	0.000000	0.000000
ME10	1.800000	0.000000
MC10	0.8000000	0.000000
ME12	0.1500000	0.000000
MC12	0.6000000E-01	0.000000
W3	5126.714	0.000000
W5	11126.71	0.000000
C3	12.73192	0.000000
C5	13.57219	0.000000
K3	41.83491	0.000000
K5	43.65005	0.000000
N3	517.8841	0.000000
N5	515.5275	0.000000
C10	0.000000	0.000000
K10	0.000000	0.000000
N10	0.000000	0.000000
W9	2225.343	0.000000
C9	13.57219	0.000000
K9	43.65005	0.000000
N9	515.5275	0.000000
C12	0.000000	0.000000
K12	0.000000	0.000000
N12	0.000000	0.000000
W11	1201.685	0.000000
W15	1201.685	0.000000
C15	0.2714438	0.000000
K15	0.3492004	0.000000
N15	0.4124220	0.000000
W14	0.000000	0.000000
C14	0.6514652	0.000000
K14	1.222201	0.000000
N14	1.031055	0.000000
SALTCAKE	56.25000	0.000000
W18	0.000000	0.000000
W17	0.000000	0.000000
C17	12.83153	0.000000
K17	42.10416	0.000000
N17	532.3091	0.000000
W13	1201.685	0.000000
K13	12.13471	0.000000
C13	6.758951	0.000000
N13	79.39124	0.000000
W16	0.000000	0.000000
SSBL	2235.134	0.000000
SMELT	1129.114	0.000000
W19	6402.079	0.000000
C19	1.745088	0.000000
K19	5.726166	0.000000
N19	101.5053	0.000000

W20	6402.079	0.000000
C20	14.57662	0.000000
K20	47.83033	0.000000
N20	633.8143	0.000000
W21	6350.862	0.000000
C21	12.57962	0.000000
K21	42.09069	0.000000
N21	613.5323	0.000000
W22	51.21663	0.000000
C22	1.996997	0.000000
K22	5.739640	0.000000
N22	20.28206	0.000000
W23	3.841247	0.000000
N23	0.9603119	0.000000
C23	0.3841247E-01	0.000000
K23	0.3841247E-02	0.000000
W32	1016.138	0.000000
C32	2.981371	0.000000
K32	0.6734510	0.000000
N32	95.71103	0.000000
W25	423.3055	0.000000
C25	3.194867	0.000000
K25	0.6830831	0.000000
N25	13.52750	0.000000
K26	0.4233055E-01	0.000000
W26	423.3055	0.000000
C26	0.4233055E-01	0.000000
N27	0.6763751	0.000000
W27	0.000000	0.000000
C27	3.152536	0.000000
K27	0.6407526	0.000000
N26	12.85113	0.000000
W29	31.75431	0.000000
C29	0.000000	0.000000
K29	0.000000	0.000000
N29	0.000000	0.000000
W28	8.256121	0.000000
C28	0.1886944E-01	0.000000
K28	0.2230807	0.000000
N28	0.6135323	0.000000
LIME	525.0000	0.000000
WATERSLK	168.0000	0.000000
W30	6142.852	0.000000
C30	15.71329	0.000000
K30	42.50836	0.000000
N30	613.5951	0.000000
W31	6142.852	0.000000
C31	15.71329	0.000000
K31	42.50836	0.000000
N31	613.5951	0.000000

APPENDIX B
LINGO MODEL FOR THE REVERSE PROBLEM FORMULATION OF BAHR EL-BAQAR DRAINAGE SYSTEM AND LAKE MANZALA

! KT1_1_6 is the kinetic rate constant;

```
KT1_1_6 = 0.9041909E-05 ;

!min = (c15_6 - 1.17)^2;

max = CPnew;

QPnew = 2;
!CPnew = 18.7;
C15_6 <= 1.3;
Daily_Initial_load = QPnew*(12.5)*0.001*60*60*24; !kg/d;
!Case 1 is in reach 15;
!Cost1 = 10E06 + 21*2*(12.5 - CPnew)*0.001*3600*8760;

!Case 2 is in reach 12;
!Cost2 = 17E06 + 21*2*(12.5 - CPnew)**0.0013600*8760;
!Case 3 is in reach 10;
!Cost3 = 35E06 + 21*2*(12.5 - CPnew)*0.001*3600*8760;
!Case 4 is in reach 4;
Cost4 = 18E06 + 21*2*(12.5 - CPnew)*0.001*3600*8760;

KT1_1_6 = K2_1_6 ; K2_1_6 = K3_1_6 ; K3_1_6 = K4_1_6 ;
K4_1_6 = K5_1_6 ;  K5_1_6 = K1_2_6 ; K1_2_6 = K2_2_6 ;
K2_2_6 = K3_2_6 ;  K3_2_6 = K1_3_6 ; K1_3_6 = K2_3_6 ;
K2_3_6 = K3_3_6 ;  K3_3_6 = K4_3_6 ; K4_3_6 = K1_4_6 ;
K1_4_6 = K2_4_6 ;  K2_4_6 = K3_4_6 ; K3_4_6 = K4_4_6 ;
K4_4_6 = K5_4_6;   K5_4_6 = K6_4_6;  K6_4_6 = K1_5_6;
K1_5_6 = K2_5_6 ;  K2_5_6 = K3_5_6 ; K3_5_6 = K4_5_6 ;
K4_5_6 = K5_5_6 ;  K5_5_6 = K1_6_6 ; K1_6_6 = K2_6_6;
K2_6_6 = K3_6_6 ;  K3_6_6 = K4_6_6 ; K4_6_6 = K1_7_6 ;
K1_7_6 = K2_7_6 ;  K2_7_6 = KT3_7_6 ;KT3_7_6 = K1_8_6 ;
K1_8_6 =  K2_8_6 ; K2_8_6 = K3_8_6 ; K3_8_6 = KT1_9_6 ;
KT1_9_6 = K2_9_6;  K2_9_6 = K1_10_6; K1_10_6 = K2_10_6 ;
K2_10_6 = K1_11_6; K1_11_6 = K2_11_6; K2_11_6 = K3_11_6 ;
K3_11_6 = K1_12_6; K1_12_6 = K2_12_6; K2_12_6 = K3_12_6;
K3_12_6 = K2_13_6; K2_13_6 =KB8_6;    KB8_6 = KB9_6;
KB9_6 = KQ1_6;  KQ1_6 = KQ2_6;   KQ2_6 = KQ3_6;
KQ3_6 = KQ4_6;  KQ4_6 = KQ5_6;   KQ5_6 = KQ6_6;
KQ6_6 = KQ7_6;  KQ7_6 = KB10_6;  KB10_6 = KR11_6;
KR11_6 = KR12_6; KR12_6 = KR13_6; KR13_6=KR14_6;
KR14_6 = KR15_6; KR15_6 =KT1_1_6 ;
```

```
!in this scenario CDrainage=4 from reach 1-6 then=2 till the end,
CSanitary treated,ST=40;
! the Reach 8 was considered a diffuse source mixed of raw sewage and
agricultural drainage and !their is no reuse in the tributaries of
reach 8 ;
!Data for tributary 1 (Sindibis), Reach 1(Qaliobiya), June;
SU1_1_6 = 0.00;
ST1_1_6 = 1.09;
I1_1_6 = 0.0;
Alfa1_1_6 = 0.000066;
A1_1 = 3650;
Beta1_1_6= 0.000023;
!Equations for tributary 1 (Sindibis), Reach 1(Qaliobiya), June;
T1_1_6 = SU1_1_6 + ST1_1_6 + I1_1_6 + D1_1_6 - U1_1_6;
D1_1_6 = Alfa1_1_6*A1_1;
U1_1_6 = Beta1_1_6*A1_1;

!Data for tributary 2 (Iskandar), Reach 1(Qaliobiya), June;
SU2_1_6 = 0.00;
ST2_1_6 = 0.00;
I2_1_6 = 0.00;
Alfa2_1_6 = 0.000066;
A2_1 = 10200;
Beta2_1_6= 0.000023;
!Equations for tributary 2 (Iskandar), Reach 1(Qaliobiya), June;
T2_1_6 = SU2_1_6 + ST2_1_6 + I2_1_6 + D2_1_6 - U2_1_6;
D2_1_6 = Alfa2_1_6*A2_1;
U2_1_6 = Beta2_1_6*A2_1;

!Data for tributary 3 (Qoronfil), Reach 1(Qaliobiya), June;
SU3_1_6 = 0.00;
ST3_1_6 = 0.00;
I3_1_6 = 0.00;
Alfa3_1_6 = 0.000066;
A3_1 = 2300;
Beta3_1_6= 0.000023;
!Equations for tributary 3 (Qoronfil), Reach 1(Qaliobiya), June;
T3_1_6 = SU3_1_6 + ST3_1_6 + I3_1_6 + D3_1_6 - U3_1_6;
D3_1_6 = Alfa3_1_6*A3_1;
U3_1_6 = Beta3_1_6*A3_1;

!Data for tributary 4 (Aghour), Reach 1(Qaliobiya), June;
SU4_1_6 = 0.00;
ST4_1_6 = 0.00;
I4_1_6 = 0.00;
Alfa4_1_6 = 0.000066;
A4_1 = 950;
Beta4_1_6= 0.000023;
!Equations for tributary 4 (Aghour), Reach 1(Qaliobiya), June;
T4_1_6 = SU4_1_6 + ST4_1_6 + I4_1_6 + D4_1_6 - U4_1_6;
D4_1_6 = Alfa4_1_6*A4_1;
U4_1_6 = Beta4_1_6*A4_1;
```

```
!Data for tributary 5 (Namol), Reach 1(Qaliobiya), June;
SU5_1_6 = 0.00;
ST5_1_6 = 0.00;
I5_1_6 = 0.00;
Alfa5_1_6 = 0.000066;
A5_1 = 9000;
Beta5_1_6= 0.000023;
!Equations for tributary 5 (Namol), Reach 1(Qaliobiya), June;
T5_1_6 = SU5_1_6 + ST5_1_6 + I5_1_6 + D5_1_6 - U5_1_6;
D5_1_6 = Alfa5_1_6*A5_1;
U5_1_6 = Beta5_1_6*A5_1;
!Data for Reach 1 (Qaliobiya), June;
Q0_6 = 0.6;
P1_6 = 0.0;
L1_6 = 0.0;
I1_6=0.00;
D1_6 = 0.0133;
!Equation for Reach 1 (Qaliobiya), June;
Q1_6 = Q0_6 + P1_6 - L1_6 + D1_6+I1_6 + T1_1_6 + T2_1_6 + T3_1_6 +
T4_1_6 + T5_1_6;

!Data for tributary 1 (Sindibis), Reach 1(Qaliobiya), June;
!KT1_1_6 = 1;
!KT1_1_6 = 0.28/86400;
Tau1_1_6= 0.77;
Cin1_1_6 = 9.5;
CT1_1_6- Cin1_1_6*(@exp(-kT1_1_6*Tau1_1_6)) =0;

!Data for tributary 2 (Iskandar), Reach 1(Qaliobiya), June;
CSU2_1_6 = 12.5;
CST2_1_6 = 9.5;
CI2_1_6 = 10;
CD2_1_6 = 1.5;
CU2_1_6 - CT2_1_6 = 0;
R2_1_6 = K2_1_6*CT2_1_6;
!K2_1_6 = 0.28/86400;
V2_1_6 = 22526;
!Equations for tributary 2 (Iskandar), Reach 1(Qaliobiya), June;
T2_1_6*CT2_1_6 = SU2_1_6 *CSU2_1_6 + ST2_1_6*CST2_1_6+ I2_1_6*CI2_1_6
+ D2_1_6*CD2_1_6 - U2_1_6*CU2_1_6 - R2_1_6*V2_1_6;

!Data for tributary 3 (Qoronfil), Reach 1(Qaliobiya), June;
CSU3_1_6 = 12.5;
CST3_1_6 = 9.5;
CI3_1_6 = 10;
CD3_1_6 = 1.5;
CU3_1_6 - CT3_1_6 = 0;
R3_1_6 = K3_1_6*CT3_1_6;
!K3_1_6 = 0.28/86400;
V3_1_6 = 2141;
!Equations for tributary 3 (Qoronfil ),Reach 1(Qaliobiya), June;
T3_1_6*CT3_1_6 = SU3_1_6* CSU3_1_6 + ST3_1_6*CST3_1_6+ I3_1_6*CI3_1_6
+ D3_1_6*CD3_1_6 - U3_1_6*CU3_1_6 - R3_1_6*V3_1_6;
```

```
!Data for tributary 4 (Aghour), Reach 1(Qaliobiya), June;
CSU4_1_6 = 12.5; !untreated;
CST4_1_6 = 9.5; !treated;
CI4_1_6 = 10; !industrial';
CD4_1_6 = 1.5; !agricultural;
CU4_1_6 - CT4_1_6 = 0;
R4_1_6 = K4_1_6*CT4_1_6;
!K4_1_6 = 0.28/86400;
V4_1_6 = 280;
!Equations for tributary 4 (Aghour),Reach 1(Qaliobiya), June;
T4_1_6*CT4_1_6= SU4_1_6* CSU4_1_6 + ST4_1_6*CST4_1_6+ I4_1_6*CI4_1_6 +
D4_1_6*CD4_1_6 - U4_1_6*CU4_1_6 - R4_1_6*V4_1_6;

!Data for tributary 5 (Namoul), Reach 1(Qaliobiya), June;
CSU5_1_6 = 12.5;   !phosphorus value for untreated sewage;
CST5_1_6 = 9.5;  ! phosphorus value for treated sewage;
CI5_1_6 = 10;  !phosphorus value for industrial discharge;
CD5_1_6 = 1.5;
CU5_1_6 - CT5_1_6 = 0;
R5_1_6 = K5_1_6*CT5_1_6;
!K5_1_6 = 0.28/86400;
V5_1_6 = 28186;
!Equations for tributary 5 (Namoul),Reach 1(Qaliobiya), June;
T5_1_6*CT5_1_6 = SU5_1_6* CSU5_1_6 + ST5_1_6*CST5_1_6+ I5_1_6*CI5_1_6
+ D5_1_6*CD5_1_6 - U5_1_6*CU5_1_6 - R5_1_6*V5_1_6;

!Data for Reach 1 Qalyoubia;
C0_6 =1;
CP1_6 = 1;
CL1_6 = 1;
CD1_6=1.5;
CI1_6=10;
RQ1_6=KQ1_6*C1_6;
!KQ1_6=0.28/86400;
VQ1_6=49418;
!Equation for Reach 1 (Qaliobiya), June;
Q1_6*C1_6 = Q0_6*C0_6 + P1_6*CP1_6 - L1_6*CL1_6+I1_6*CI1_6 +
D1_6*CD1_6- RQ1_6*VQ1_6 + T1_1_6*CT1_1_6 + T2_1_6*CT2_1_6 +
T3_1_6*CT3_1_6 + T4_1_6*CT4_1_6 + T5_1_6*CT5_1_6;

!Data for tributary 1 (Shebeen), Reach 2(Qaliobiya), June;
SU1_2_6 = 0.00;
ST1_2_6 = 3.47;
I1_2_6 = 1.0;
Alfa1_2_6 = 0.000066;
A1_2 = 40000;
Beta1_2_6= 0.000023;
! Equations for tributary 1 (Shebeen), Reach 2(Qaliobiya), June;
T1_2_6 = SU1_2_6 + ST1_2_6 + I1_2_6 + D1_2_6 - U1_2_6;
D1_2_6 = Alfa1_2_6*A1_2;
U1_2_6 = Beta1_2_6*A1_2;
```

```
!Data for tributary 2 (El Manzala), Reach 2(Qaliobiya), June;
SU2_2_6 = 0.00;
ST2_2_6 = 0.11;
I2_2_6 = 0.00;
Alfa2_2_6 = 0.000066;
A2_2 = 1900;
Beta2_2_6= 0.000023;
!Equations for tributary 2 (El Manzala), Reach 1(Qaliobiya), June;
T2_2_6 = SU2_2_6 + ST2_2_6 + I2_2_6 + D2_2_6 - U2_2_6;
D2_2_6 = Alfa2_2_6*A2_2;
U2_2_6 = Beta2_2_6*A2_2;

!Data for tributary 3 (El Modeer), Reach 2(Qaliobiya), June;
SU3_2_6 = 0.00;
ST3_2_6 = 0.00;
I3_2_6 = 0.00;
Alfa3_2_6 = 0.000066;
A3_2 = 5700;
Beta3_2_6= 0.000023;
!Equations for tributary 3 (El Modeer), Reach 2(Qaliobiya), June;
T3_2_6 = SU3_2_6 + ST3_2_6 + I3_2_6 + D3_2_6 - U3_2_6;
D3_2_6 = Alfa3_2_6*A3_2;
U3_2_6 = Beta3_2_6*A3_2;

!Data for Reach 2 (Qaliobiya), June;
P2_6 = 0.0;
I2_6=0.00;
L2_6 = 0.0;
D2_6 = 0.0497;

!Equation for Reach 2 (Qaliobiya), June;
Q2_6 = Q1_6 + P2_6 - L2_6 + D2_6+I2_6 + T1_2_6 + T2_2_6 + T3_2_6;

!Data for tributary 1 (Shebeen el Qanater), Reach 2(Qaliobiya), June;
!K1_2_6 = 0.28/86400;
Tau1_2_6= 1.02;
CST1_2_6=9.5;
CSU1_2_6=12.5;
CD1_2_6=1.5;
CI1_2_6=10;
CU1_2_6-CT1_2_6=0;
R1_2_6=K1_2_6*CT1_2_6;
V1_2_6=498678;
!Equations for tributary 1 (Shebeen el Qanater), Reach 2(Qaliobiya),
June;
T1_2_6*CT1_2_6=ST1_2_6*CST1_2_6+ SU1_2_6*CSU1_2_6+ D1_2_6*CD1_2_6-
U1_2_6*CU1_2_6-R1_2_6*V1_2_6;

!Data for tributary 2 (El Manzala), Reach 2(Qaliobiya), June;
CSU2_2_6 = 12.5;
CST2_2_6 = 9.5;
CI2_2_6 = 10;
CD2_2_6 = 1.5;
```

```
CU2_2_6 - CT2_2_6 = 0;
R2_2_6 = K2_2_6*CT2_2_6;
!K2_2_6 = 0.28/86400;
V2_2_6 = 3448;
!Equations for tributary 2 (El Manzala), Reach 2(Qaliobiya), June;
T2_2_6*CT2_2_6 = SU2_2_6* CSU2_2_6 + ST2_2_6*CST2_2_6+ I2_2_6*CI2_2_6
+ D2_2_6*CD2_2_6 - U2_2_6*CU2_2_6 - R2_2_6*V2_2_6;

!Data for tributary 3 (El Modeer), Reach 2(Qaliobiya), June;
CSU3_2_6 = 12.5;
CST3_2_6 = 9.5;
CI3_2_6 = 10;
CD3_2_6 = 1.5;
CU3_2_6 - CT3_2_6 = 0;
R3_2_6 = K3_2_6*CT3_2_6;
!K3_2_6 = 0.28/86400;
V3_2_6 = 12644;
!Equations for tributary 3 (El Modeer), Reach 2(Qaliobiya), June;
T3_2_6*CT3_2_6 = SU3_2_6* CSU3_2_6 + ST3_2_6*CST3_2_6+ I3_2_6*CI3_2_6
+ D3_2_6*CD3_2_6 - U3_2_6*CU3_2_6 - R3_2_6*V3_2_6;

!Data for reach 2 Qalyoubia;
CP2_6 = 1;
CL2_6 = 1;
CI2_6=10;
CD2_6=1.5;
RQ2_6=KQ2_6*C2_6;
!KQ2_6=0.28/86400;
VQ2_6=198403;
!Equation for Reach 2 (Qaliobiya), June;
Q2_6*C2_6 = Q1_6*C1_6 + P2_6*CP2_6 - L2_6*CL2_6+I2_6*CI2_6 +
D2_6*CD2_6-RQ2_6*VQ2_6 + T1_2_6*CT1_2_6 + T2_2_6*CT2_2_6 +
T3_2_6*CT3_2_6;

!Data for tributary 1 (El Hessah), Reach 3(Qaliobiya), June;
SU1_3_6 = 0.00;
ST1_3_6 = 0.00;
I1_3_6 = 0.0;
Alfa1_3_6 = 0.000066;
A1_3 = 700;
Beta1_3_6= 0.000023;
!Equations for tributary 1 (El Hessah), Reach 3(Qaliobiya), June;
T1_3_6 = SU1_3_6 + ST1_3_6 + I1_3_6 + D1_3_6 - U1_3_6;
D1_3_6 = Alfa1_3_6*A1_3;
U1_3_6 = Beta1_3_6*A1_3;

!Data for tributary 2 (Tahla), Reach 3(Qaliobiya), June;
SU2_3_6 = 0.00;
ST2_3_6 = 0.87;
I2_3_6 = 0.0;
Alfa2_3_6 = 0.000066;
A2_3 = 31000;
Beta2_3_6= 0.000023;
```

```
!Equations for tributary 2 (Tahla), Reach 3(Qaliobiya), June;
T2_3_6 = SU2_3_6 + ST2_3_6 + I2_3_6 + D2_3_6 - U2_3_6;
D2_3_6 = Alfa2_3_6*A2_3;
U2_3_6 = Beta2_3_6*A2_3;

!Data for tributary 3 (Marsafa), Reach 3(Qaliobiya), June;
SU3_3_6 = 0.00;
ST3_3_6 = 0.00;
I3_3_6 = 0.0;
Alfa3_3_6 = 0.000066;
A3_3 = 2300;
Beta3_3_6= 0.000023;
! Equations for tributary 3 (Marsafa), Reach 3(Qaliobiya), June;
T3_3_6 = SU3_3_6 + ST3_3_6 + I3_3_6 + D3_3_6 - U3_3_6;
D3_3_6 = Alfa3_3_6*A3_3;
U3_3_6 = Beta3_3_6*A3_3;

!Data for tributary 4 (El Sanafen el Qebly), Reach 3(Qaliobiya), June;
SU4_3_6 = 0.00;
ST4_3_6 = 0.00;
I4_3_6 = 0.0;
Alfa4_3_6 = 0.000066;
A4_3 = 2700;
Beta4_3_6= 0.000023;
! Equations for tributary 4 (El Sanafen el Qebly), Reach 3(Qaliobiya),
June;
T4_3_6 = SU4_3_6 + ST4_3_6 + I4_3_6 + D4_3_6 - U4_3_6;
D4_3_6 = Alfa4_3_6*A4_3;
U4_3_6 = Beta4_3_6*A4_3;


!Data for Reach 3 (Qaliobiya), June;
P3_6 = 0.0;
L3_6 = 0.0;
D3_6 = 0.0133;
I3_6=0.00;
!Equation for Reach 3 (Qaliobiya), June;
Q3_6 = Q2_6 + P3_6 - L3_6 + D3_6+I3_6 + T1_3_6 + T2_3_6 + T3_3_6+
T4_3_6 ;

!Data for tributary 1 (el Hessah), Reach 3(Qaliobiya), June;
CSU1_3_6 = 12.5;
CST1_3_6 = 9.5;
CI1_3_6 = 10;
CD1_3_6 = 1.5;
CU1_3_6 - CT1_3_6 = 0;
R1_3_6 = K1_3_6*CT1_3_6;
!K1_3_6 = 0.28/86400;
V1_3_6 = 1389;
!Equations for tributary 1 (el Hessah), Reach 3 (Qaliobiya), June;
T1_3_6*CT1_3_6 = SU1_3_6* CSU1_3_6 + ST1_3_6*CST1_3_6+ I1_3_6*CI1_3_6
+ D1_3_6*CD1_3_6 - U1_3_6*CU1_3_6 - R1_3_6*V1_3_6;
```

```
!Data for tributary 2 (Tahla), Reach 3(Qaliobiya), June;
CSU2_3_6 = 12.5;
CST2_3_6 = 9.5;
CI2_3_6 = 10;
CD2_3_6 = 1.5;
CU2_3_6 - CT2_3_6 = 0;
R2_3_6 = K2_3_6*CT2_3_6;
!K2_3_6 = 0.28/86400;
V2_3_6 = 232234;
!Equations for tributary 2 (Tahla), Reach 3(Qaliobiya), June;
T2_3_6*CT2_3_6 = SU2_3_6* CSU2_3_6 + ST2_3_6*CST2_3_6+ I2_3_6*CI2_3_6
+ D2_3_6*CD2_3_6 - U2_3_6*CU2_3_6 - R2_3_6*V2_3_6;

!Data for tributary 3 (Marsafa), Reach 3(Qaliobiya), June;
CSU3_3_6 = 12.5;
CST3_3_6 = 9.5;
CI3_3_6 = 10;
CD3_3_6 = 1.5;
CU3_3_6 - CT3_3_6 = 0;
R3_3_6 = K3_3_6*CT3_3_6;
!K3_3_6 = 0.28/86400;
V3_3_6 = 2211;
! Equations for tributary 3 (Marsafa), Reach 3(Qaliobiya), June;
T3_3_6*CT3_3_6 = SU3_3_6* CSU3_3_6 + ST3_3_6*CST3_3_6+ I3_3_6*CI3_3_6
+ D3_3_6*CD3_3_6 - U3_3_6*CU3_3_6 - R3_3_6*V3_3_6;

!Data for tributary 4 (El Sanafen el Qebly), Reach 3(Qaliobiya), June;
CSU4_3_6 = 12.5;
CST4_3_6 = 9.5;
CI4_3_6 = 10;
CD4_3_6 = 1.5;
CU4_3_6 - CT4_3_6 = 0;
R4_3_6 = K4_3_6*CT4_3_6;
!K4_3_6 = 0.28/86400;
V4_3_6 =2316;
! Equations for tributary 4 (El Sanafen el Qebly), Reach 3(Qaliobiya),
June;
T4_3_6*CT4_3_6 = SU4_3_6* CSU4_3_6 + ST4_3_6*CST4_3_6+ I4_3_6*CI4_3_6
+ D4_3_6*CD4_3_6 - U4_3_6*CU4_3_6 - R4_3_6*V4_3_6;

!Data for Reach 3 (Qaliobiya), June;
CP3_6 = 1;
CL3_6 = 1;
CI3_6=10;
CD3_6=1.5;
RQ3_6=KQ3_6*C3_6;
!KQ3_6=0.28/86400;
VQ3_6=265488;
!Equation for Reach 3 (Qaliobiya), June;
Q3_6*C3_6 = Q2_6*C2_6 + P3_6*CP3_6 - L3_6*CL3_6+I3_6*CI3_6 +
D3_6*CD3_6-RQ3_6*VQ3_6 + T1_3_6*CT1_3_6 + T2_3_6*CT2_3_6 +
T3_3_6*CT3_3_6+ T4_3_6*CT4_3_6;
```

```
!Data for tributary 1 (Atmedah), Reach 4(Qaliobiya), June;
SU1_4_6 = 0.00;
ST1_4_6 = 0.00;
I1_4_6 = 0.0;
Alfa1_4_6 = 0.000066;
A1_4 = 400;
Beta1_4_6= 0.000023;
!Equations for tributary 1 (Atmedah), Reach 4 (Qaliobiya), June;
T1_4_6 = SU1_4_6 + ST1_4_6 + I1_4_6 + D1_4_6 - U1_4_6;
D1_4_6 = Alfa1_4_6*A1_4;
U1_4_6 = Beta1_4_6*A1_4;

!Data for tributary 2 (El Sanafen El Bahary), Reach 4(Qaliobiya),
June;
SU2_4_6 = 0.00;
ST2_4_6 = 0.00;
I2_4_6 = 0.0;
Alfa2_4_6 = 0.000066;
A2_4 = 2600;
Beta2_4_6=0.000023;
!Equations for tributary 2 (El Sanafen El Bahary), Reach 4
(Qaliobiya), June;
T2_4_6 = SU2_4_6 + ST2_4_6 + I2_4_6 + D2_4_6 - U2_4_6;
D2_4_6 = Alfa2_4_6*A2_4;
U2_4_6 = Beta2_4_6*A2_4;

!Data for tributary 3 (El Qalzam), Reach 4(Qaliobiya), June;
SU3_4_6 = 0.00;
ST3_4_6 = 0.00;
I3_4_6 = 0.0;
Alfa3_4_6 = 0.000066;
A3_4 = 18000;
Beta3_4_6= 0.000023;
!Equations for tributary 3 (El Qalzam), Reach 4 (Qaliobiya), June;
T3_4_6 = SU3_4_6 + ST3_4_6 + I3_4_6 + D3_4_6 - U3_4_6;
D3_4_6 = Alfa3_4_6*A3_4;
U3_4_6 = Beta3_4_6*A3_4;

!Data for tributary 4 (Kafr Salamah), Reach 4(Qaliobiya), June;
SU4_4_6 = 0.00;
ST4_4_6 = 0.00;
I4_4_6 = 0.0;
Alfa4_4_6 = 0.000066;
A4_4 = 3500;
Beta4_4_6= 0.000023;
!Equations for tributary 4 (Kafr Salamah), Reach 4 (Qaliobiya), June;
T4_4_6 = SU4_4_6 + ST4_4_6 + I4_4_6 + D4_4_6 - U4_4_6;
D4_4_6 = Alfa4_4_6*A4_4;
U4_4_6 = Beta4_4_6*A4_4;

!Data for tributary 5 (Sanhout El Berak), Reach 4(Qaliobiya), June;
SU5_4_6 = 0.00;
ST5_4_6 = 0.00;
```

```
I5_4_6 = 0.0;
Alfa5_4_6 = 0.000066;
A5_4 = 1400;
Beta5_4_6= 0.000023;
!Equations for tributary 5 (Sanhout El Berak), Reach 4 (Qaliobiya),
June;
T5_4_6 = SU5_4_6 + ST5_4_6 + I5_4_6 + D5_4_6 - U5_4_6;
D5_4_6 = Alfa5_4_6*A5_4;
U5_4_6 = Beta5_4_6*A5_4;

!Data for tributary 6 (Abou  El Eyal), Reach 4(Qaliobiya), June;
SU6_4_6 = 0.00;
ST6_4_6 = 0.00;
I6_4_6 = 0.0;
Alfa6_4_6 = 0.000066;
A6_4 = 500;
Beta6_4_6= 0.000023;
!Equations for tributary 6 (Abou  El Eyal), Reach 4 (Qaliobiya), June;
T6_4_6 = SU6_4_6 + ST6_4_6 + I6_4_6 + D6_4_6 - U6_4_6;
D6_4_6 = Alfa6_4_6*A6_4;
U6_4_6 = Beta6_4_6*A6_4;

!Data for Reach 4 (Qaliobiya), June;
P4_6 = 0.0;
L4_6 = 0.0;
D4_6 = 0.01862;
I4_6=0.00;
!Equation for Reach 4 (Qaliobiya), June;
Q4_6 = Q3_6 + P4_6 - L4_6 + D4_6+I4_6 + T1_4_6 + T2_4_6 + T3_4_6+
T4_4_6+ T5_4_6+ T6_4_6+ QPnew ;

!Data for tributary 1 (Atmedah), Reach 4(Qaliobiya), June;
CSU1_4_6 = 12.5;
CST1_4_6 = 9.5;
CI1_4_6 = 10;
CD1_4_6 = 1.5;
CU1_4_6 - CT1_4_6 = 0;
R1_4_6 = K1_4_6*CT1_4_6;
!K1_4_6 = 0.28/86400;
V1_4_6 = 996;
!Equations for tributary 1 (Atmedah), Reach 4 (Qaliobiya), June;
T1_4_6*CT1_4_6 = SU1_4_6* CSU1_4_6 + ST1_4_6*CST1_4_6+ I1_4_6*CI1_4_6
+ D1_4_6*CD1_4_6 - U1_4_6*CU1_4_6 - R1_4_6*V1_4_6;

!Data for tributary 2 (El Sanafen El Bahary), Reach 4(Qaliobiya),
June;
CSU2_4_6 = 12.5;
CST2_4_6 = 9.5;
CI2_4_6 =10;
CD2_4_6 = 1.5;
CU2_4_6 - CT2_4_6 = 0;
R2_4_6 = K2_4_6*CT2_4_6;
!K2_4_6 = 0.28/86400;
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```
V2_4_6 =2530;
!Equations for tributary 2 (El Sanafen El Bahary), Reach 4
(Qaliobiya), June;
T2_4_6*CT2_4_6 = SU2_4_6* CSU2_4_6 + ST2_4_6*CST2_4_6+ I2_4_6*CI2_4_6
+ D2_4_6*CD2_4_6 - U2_4_6*CU2_4_6 - R2_4_6*V2_4_6;

!Data for tributary 3 (El Qalzam), Reach 4(Qaliobiya), June;
CSU3_4_6 = 12.5;
CST3_4_6 = 9.5;
CI3_4_6 = 10;
CD3_4_6 = 1.5;
CU3_4_6 - CT3_4_6 = 0;
R3_4_6 = K3_4_6*CT3_4_6;
!K3_4_6 = 0.28/86400;
V3_4_6 = 31982;
!Equations for tributary 3 (El Qalzam), Reach 4 (Qaliobiya), June;
T3_4_6*CT3_4_6 = SU3_4_6* CSU3_4_6 + ST3_4_6*CST3_4_6+ I3_4_6*CI3_4_6
+ D3_4_6*CD3_4_6 - U3_4_6*CU3_4_6 - R3_4_6*V3_4_6;

!Data for tributary 4 (Kafr Salamah), Reach 4(Qaliobiya), June;
CSU4_4_6 = 12.5;
CST4_4_6 = 9.5;
CI4_4_6 = 10;
CD4_4_6 = 1.5;
CU4_4_6 - CT4_4_6 = 0;
R4_4_6 = K4_4_6*CT4_4_6;
!K4_4_6 = 0.28/86400;
V4_4_6=3484;
!Equations for tributary 4 (Kafr Salamah), Reach 4 (Qaliobiya), June;
T4_4_6*CT4_4_6 = SU4_4_6* CSU4_4_6 + ST4_4_6*CST4_4_6+ I4_4_6*CI4_4_6
+ D4_4_6*CD4_4_6 - U4_4_6*CU4_4_6 - R4_4_6*V4_4_6;

!Data for tributary 5 (Sanhout El Berak), Reach 4(Qaliobiya), June;
CSU5_4_6 = 12.5;
CST5_4_6 = 9.5;
CI5_4_6 = 10;
CD5_4_6 = 1.5;
CU5_4_6 - CT5_4_6 = 0;
R5_4_6 = K5_4_6*CT5_4_6;
!K5_4_6 = 0.28/86400;
V5_4_6 =1766;
!Equations for tributary 5 (Sanhout El Berak), Reach 4 (Qaliobiya),
June;
T5_4_6*CT5_4_6 = SU5_4_6* CSU5_4_6 + ST5_4_6*CST5_4_6+ I5_4_6*CI5_4_6
+ D5_4_6*CD5_4_6 - U5_4_6*CU5_4_6 - R5_4_6*V5_4_6;
!Data for tributary 6 (Abou  El Eyal), Reach 4(Qaliobiya), June;
CSU6_4_6 = 12.5;
CST6_4_6 = 9.5;
CI6_4_6 = 10;
CD6_4_6 = 1.5;
CU6_4_6 - CT6_4_6 = 0;
R6_4_6 = K6_4_6*CT6_4_6;
!K6_4_6 = 0.28/86400;
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V6_4_6=755;
!Equations for tributary 6 (Abou  El Eyal), Reach 4 (Qaliobiya), June;
T6_4_6*CT6_4_6 = SU6_4_6* CSU6_4_6 + ST6_4_6*CST6_4_6+ I6_4_6*CI6_4_6
+ D6_4_6*CD6_4_6 - U6_4_6*CU6_4_6 - R6_4_6*V6_4_6;

!Data for Reach 4 (Qaliobiya), June;
CP4_6 = 1;
CL4_6 = 1;
CD4_6=1.5;
CI4_6=10;
RQ4_6=KQ4_6*C4_6;
!KQ4_6=0.28/86400;
VQ4_6=268351;

!Equation for Reach 4 (Qaliobiya), June;
Q4_6*C4_6 = Q3_6*C3_6 + P4_6*CP4_6 - L4_6*CL4_6+I4_6*CI4_6 +
D4_6*CD4_6-RQ4_6*VQ4_6 + T1_4_6*CT1_4_6 + T2_4_6*CT2_4_6 +
T3_4_6*CT3_4_6+ T4_4_6*CT4_4_6+ QPnew*CPnew;

!Data for tributary 1 (Meit Yazeed), Reach 5(Qaliobiya), June;
SU1_5_6 = 0.00;
ST1_5_6 = 0.00;
I1_5_6 = 0.0;
Alfa1_5_6 = 0.000066;
A1_5 = 8000;
Beta1_5_6= 0.000023;
! Equations for tributary 1 (Meit Yazeed), Reach 5 (Qaliobiya), June;
T1_5_6 = SU1_5_6 + ST1_5_6 + I1_5_6 + D1_5_6 - U1_5_6;
D1_5_6 = Alfa1_5_6*A1_5;
U1_5_6 = Beta1_5_6*A1_5;

!Data for tributary 2 (El Saadyeen), Reach 5(Qaliobiya), June;
SU2_5_6 = 0.00;
ST2_5_6 = 0.00;
I2_5_6 = 0.0;
Alfa2_5_6 = 0.000066;
A2_5 = 2400;
Beta2_5_6= 0.000023;
!Equations for tributary 2 (El Saadyeen), Reach 5 (Qaliobiya), June;
T2_5_6 = SU2_5_6 + ST2_5_6 + I2_5_6 + D2_5_6 - U2_5_6;
D2_5_6 = Alfa2_5_6*A2_5;
U2_5_6 = Beta2_5_6*A2_5;

!Data for tributary 3 (Shalshalamon), Reach 5(Qaliobiya), June;
SU3_5_6 = 0.00;
ST3_5_6 = 0.00;
I3_5_6 = 0.0;
Alfa3_5_6 = 0.000066;
A3_5 = 2100;
Beta3_5_6= 0.000023;
!Equations for tributary 3 (Shalshalamon), Reach 5 (Qaliobiya), June;
T3_5_6 = SU3_5_6 + ST3_5_6 + I3_5_6 + D3_5_6 - U3_5_6;
D3_5_6 = Alfa3_5_6*A3_5;
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U3_5_6 = Beta3_5_6*A3_5;

!Data for tributary 4 (Kafr El Maaly), Reach 5(Qaliobiya), June;
SU4_5_6 = 0.00;
ST4_5_6 = 0.00;
I4_5_6 = 0.0;
Alfa4_5_6 = 0.000066;
A4_5 = 750;
Beta4_5_6= 0.000023;
!Equations for tributary 4 (Kafr El Maaly), Reach 5 (Qaliobiya), June;
T4_5_6 = SU4_5_6 + ST4_5_6 + I4_5_6 + D4_5_6 - U4_5_6;
D4_5_6 = Alfa4_5_6*A4_5;
U4_5_6 = Beta4_5_6*A4_5;

!Data for tributary 5 (Salamah Besharah), Reach 5(Qaliobiya), June;
SU5_5_6 = 0.00;
ST5_5_6 = 0.00;
I5_5_6 = 0.0;
Alfa5_5_6 = 0.000066;
A5_5 = 900;
Beta5_5_6= 0.000023;
!Equations for tributary 5 (Salamah Besharah), Reach 5 (Qaliobiya),
June;
T5_5_6 = SU5_5_6 + ST5_5_6 + I5_5_6 + D5_5_6 - U5_5_6;
D5_5_6 = Alfa5_5_6*A5_5;
U5_5_6 = Beta5_5_6*A5_5;

!Data for Reach 5 (Qaliobiya), June;
P5_6 = 0.0;
L5_6 = 0.0;
I5_6=0.00;
DSA5_6 = 0.23;
DAG5_6=0.0093;
!Equation for Reach 5 (Qaliobiya), June;
Q5_6 = Q4_6 + P5_6 - L5_6+I5_6 + DSA5_6+ DAG5_6 + T1_5_6 + T2_5_6 +
T3_5_6+ T4_5_6+ T5_5_6;

! Data for tributary 1 (Meit Yazeed), Reach 5(Qaliobiya), June;
CSU1_5_6 = 12.5;
CST1_5_6 = 9.5;
CI1_5_6 = 10;
CD1_5_6 = 1.5;
CU1_5_6 - CT1_5_6 = 0;
R1_5_6 = K1_5_6*CT1_5_6;
!K1_5_6 = 0.28/86400;
V1_5_6 = 20636;
!Equations for tributary 1 (Meit Yazeed), Reach 5 (Qaliobiya), June;
T1_5_6*CT1_5_6 = SU1_5_6* CSU1_5_6 + ST1_5_6*CST1_5_6+ I1_5_6*CI1_5_6
+ D1_5_6*CD1_5_6 - U1_5_6*CU1_5_6 - R1_5_6*V1_5_6;

!Data for tributary 2 (El Saadyeen), Reach 5(Qaliobiya), June;
CSU2_5_6 = 12.5;
CST2_5_6 = 9.5;
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CI2_5_6 = 10;
CD2_5_6 = 1.5;
CU2_5_6 - CT2_5_6 = 0;
R2_5_6 = K2_5_6*CT2_5_6;
!K2_5_6 = 0.28/86400;
V2_5_6 = 3211;
!Equations for tributary 2 (El Saadyeen), Reach 5 (Qaliobiya), June;
T2_5_6*CT2_5_6 = SU2_5_6* CSU2_5_6 + ST2_5_6*CST2_5_6+ I2_5_6*CI2_5_6
+ D2_5_6*CD2_5_6 - U2_5_6*CU2_5_6 - R2_5_6*V2_5_6;

!Data for tributary 3 (Shalshalamon), Reach 5(Qaliobiya), June;
CSU3_5_6 = 12.5;
CST3_5_6 = 9.5;
CI3_5_6 = 10;
CD3_5_6 = 1.5;
CU3_5_6 - CT3_5_6 = 0;
R3_5_6 = K3_5_6*CT3_5_6;
!K3_5_6 = 0.28/86400;
V3_5_6 = 3791;
!Equations for tributary 3 (Shalshalamon), Reach 5 (Qaliobiya), June;
T3_5_6*CT3_5_6 = SU3_5_6* CSU3_5_6 + ST3_5_6*CST3_5_6+ I3_5_6*CI3_5_6
+ D3_5_6*CD3_5_6 - U3_5_6*CU3_5_6 - R3_5_6*V3_5_6;

!Data for tributary 4 (Kafr El Maaly), Reach 5(Qaliobiya), June;
CSU4_5_6 = 12.5;
CST4_5_6 = 9.5;
CI4_5_6 = 10;
CD4_5_6 =1.5;
CU4_5_6 - CT4_5_6 = 0;
R4_5_6 = K4_5_6*CT4_5_6;
!K4_5_6 = 0.28/86400;
V4_5_6 = 1021;
!Equations for tributary 4 (Kafr El Maaly), Reach 5 (Qaliobiya), June;
T4_5_6*CT4_5_6 = SU4_5_6* CSU4_5_6 + ST4_5_6*CST4_5_6+ I4_5_6*CI4_5_6
+ D4_5_6*CD4_5_6 - U4_5_6*CU4_5_6 - R4_5_6*V4_5_6;

!Data for tributary 5 (Salamah Besharah), Reach 5(Qaliobiya), June;
CSU5_5_6 = 12.5;
CST5_5_6 = 9.5;
CI5_5_6 = 10;
CD5_5_6 = 1.5;
CU5_5_6 - CT5_5_6 = 0;
R5_5_6 = K5_5_6*CT5_5_6;
!K5_5_6 = 0.28/86400;
V5_5_6 = 788;
!Equations for tributary 5 (Salamah Besharah), Reach 5 (Qaliobiya),
June;
T5_5_6*CT5_5_6 = SU5_5_6* CSU5_5_6 + ST5_5_6*CST5_5_6+ I5_5_6*CI5_5_6
+ D5_5_6*CD5_5_6 - U5_5_6*CU5_5_6 - R5_5_6*V5_5_6;

!Data for Reach 5 (Qaliobiya), June;
CP5_6 = 1;
CL5_6 = 1;
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CI5_6=10;
CDAG5_6=1.5;
CDSA5_6 = 12.5;
RQ5_6=KQ5_6*C5_6;
!KQ5_6=0.28/86400;
VQ5_6=255062;
!Equation for Reach 5 (Qaliobiya), June;
Q5_6*C5_6 = Q4_6*C4_6 + P5_6*CP5_6 - L5_6*CL5_6+I5_6*CI5_6 +
DAG5_6*CDAG5_6 + DSA5_6*CDSA5_6-RQ5_6*VQ5_6 + T1_5_6*CT1_5_6 +
T2_5_6*CT2_5_6 + T3_5_6*CT3_5_6+ T4_5_6*CT4_5_6+ T5_5_6*CT5_5_6;

!Data for tributary 1 (El Naamnah), Reach 6(Qaliobiya), June;
SU1_6_6 = 0.00;
ST1_6_6 = 0.00;
I1_6_6 = 0.0;
Alfa1_6_6 = 0.000066;
A1_6 = 4950;
Beta1_6_6= 0.000023;
! Equations for tributary 1 (El Naamnah), Reach 6 (Qaliobiya), June;
T1_6_6 = SU1_6_6 + ST1_6_6 + I1_6_6 + D1_6_6 - U1_6_6;
D1_6_6 = Alfa1_6_6*A1_6;
U1_6_6 = Beta1_6_6*A1_6;

!Data for tributary 2 (Bahr El Shaqf), Reach 6(Qaliobiya), June;
SU2_6_6 = 0.00;
ST2_6_6 = 0.00;
I2_6_6 = 0.0;
Alfa2_6_6 = 0.000066;
A2_6 = 2700;
Beta2_6_6= 0.000023;
! Equations for tributary 2 (Bahr El Shaqf), Reach 6 (Qaliobiya),
June;
T2_6_6 = SU2_6_6 + ST2_6_6 + I2_6_6 + D2_6_6 - U2_6_6;
D2_6_6 = Alfa2_6_6*A2_6;
U2_6_6 = Beta2_6_6*A2_6;

!Data for tributary 3 (Abou El Akhdar), Reach 6(Qaliobiya), June;
SU3_6_6 = 0.00;
ST3_6_6 = 0.00;
I3_6_6 = 0.0;
Alfa3_6_6 = 0.000066;
A3_6 = 13700;
Beta3_6_6= 0.000023;
! Equations for tributary 3 (Abou El Akhdar), Reach 6 (Qaliobiya),
June;
T3_6_6 = SU3_6_6 + ST3_6_6 + I3_6_6 + D3_6_6 - U3_6_6;
D3_6_6 = Alfa3_6_6*A3_6;
U3_6_6 = Beta3_6_6*A3_6;

!Data for tributary 4 (Sandnhour), Reach 6(Qaliobiya), June;
SU4_6_6 = 0.00;
ST4_6_6 = 0.00;
I4_6_6 = 0.0;
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Alfa4_6_6 = 0.000066;
A4_6 = 61800;
Beta4_6_6= 0.000023;
! Equations for tributary 4 (Sandnhour), Reach 6 (Qaliobiya), June;
T4_6_6 = SU4_6_6 + ST4_6_6 + I4_6_6 + D4_6_6 - U4_6_6;
D4_6_6 = Alfa4_6_6*A4_6;
U4_6_6 = Beta4_6_6*A4_6;

!Data for Reach 6 (Qaliobiya), June;
P6_6 = 0.0;
L6_6 = 0.0;
I6_6=0.00;
D6_6 = 0.070;
!Equation for Reach 6 (Qaliobiya), June;
Q6_6 = Q5_6 + P6_6 - L6_6+I6_6 + D6_6 + T1_6_6 + T2_6_6 + T3_6_6+
T4_6_6;

! Data for tributary 1 (El Naamnah), Reach 6(Qaliobiya), June;
CSU1_6_6 = 12.5;
CST1_6_6 = 9.5;
CI1_6_6 = 10;
CD1_6_6 = 1.5;
CU1_6_6 - CT1_6_6 = 0;
R1_6_6 = K1_6_6*CT1_6_6;
!K1_6_6 = 0.28/86400;
V1_6_6 = 4974;
! Equations for tributary 1 (El Naamnah), Reach 6 (Qaliobiya), June;
T1_6_6*CT1_6_6 = SU1_6_6* CSU1_6_6 + ST1_6_6*CST1_6_6+ I1_6_6*CI1_6_6
+ D1_6_6*CD1_6_6 - U1_6_6*CU1_6_6 - R1_6_6*V1_6_6;

!Data for tributary 2 (Bahr El Shaqf), Reach 6(Qaliobiya), June;
CSU2_6_6 = 12.5;
CST2_6_6 = 9.5;
CI2_6_6 = 10;
CD2_6_6 = 1.5;
CU2_6_6 - CT2_6_6 = 0;
R2_6_6 = K2_6_6*CT2_6_6;
!K2_6_6 = 0.28/86400;
V2_6_6 =3256;
! Equations for tributary 2 (Bahr El Shaqf), Reach 6 (Qaliobiya),
June;
T2_6_6*CT2_6_6 = SU2_6_6* CSU2_6_6 + ST2_6_6*CST2_6_6+ I2_6_6*CI2_6_6
+ D2_6_6*CD2_6_6 - U2_6_6*CU2_6_6 - R2_6_6*V2_6_6;

!Data for tributary 3 (Abou El Akhdar), Reach 6(Qaliobiya), June;
CSU3_6_6 = 12.5;
CST3_6_6 = 9.5;
CI3_6_6 = 10;
CD3_6_6 = 1.5;
CU3_6_6 - CT3_6_6 = 0;
R3_6_6 = K3_6_6*CT3_6_6;
!K3_6_6 = 0.28/86400;
V3_6_6 = 41966;
```

```
! Equations for tributary 3 (Abou El Akhdar), Reach 6 (Qaliobiya),
June;
T3_6_6*CT3_6_6 = SU3_6_6* CSU3_6_6 + ST3_6_6*CST3_6_6+ I3_6_6*CI3_6_6
+ D3_6_6*CD3_6_6 - U3_6_6*CU3_6_6 - R3_6_6*V3_6_6;

!Data for tributary 4 (Sandnhour), Reach 6(Qaliobiya), June;
CSU4_6_6 = 12.5;
CST4_6_6 = 9.5;
CI4_6_6 = 10;
CD4_6_6 = 1.5;
CU4_6_6 - CT4_6_6 = 0;
R4_6_6 = K4_6_6*CT4_6_6;
!K4_6_6 = 0.28/86400;
V4_6_6 = 223784;
! Equations for tributary 4 (Sandnhour), Reach 6 (Qaliobiya), June;
T4_6_6*CT4_6_6 = SU4_6_6* CSU4_6_6 + ST4_6_6*CST4_6_6+ I4_6_6*CI4_6_6
+ D4_6_6*CD4_6_6 - U4_6_6*CU4_6_6 - R4_6_6*V4_6_6;

! Data for Reach 6 (Qaliobiya), June;
CP6_6 = 1;
CL6_6 = 1;
CI6_6=10;
CD6_6=1.5;
RQ6_6=KQ6_6*C6_6;
!KQ6_6=0.28/86400;
VQ6_6=381294;
!Equation for Reach 6 (Qaliobiya), June;
Q6_6*C6_6 = Q5_6*C5_6 + P6_6*CP6_6 - L6_6*CL6_6 +I6_6*C6_6+ D6_6*CD6_6
-RQ6_6*VQ6_6+ T1_6_6*CT1_6_6 + T2_6_6*CT2_6_6 + T3_6_6*CT3_6_6+
T4_6_6*CT4_6_6;

!Data for tributary 1 (Bourden), Reach 7(Qaliobiya), June;
SU1_7_6 = 0.00;
ST1_7_6 = 0.00;
I1_7_6 = 0.0;
Alfa1_7_6 = 0.000066;
A1_7 = 8700;
Beta1_7_6= 0.000011;
! Equations for tributary 1 (Bourden), Reach 7 (Qaliobiya), June;
T1_7_6 = SU1_7_6 + ST1_7_6 + I1_7_6 + D1_7_6 - U1_7_6;
D1_7_6 = Alfa1_7_6*A1_7;
U1_7_6 = Beta1_7_6*A1_7;

!Data for tributary 2 (El Khais), Reach 7(Qaliobiya), June;
SU2_7_6 = 0.00;
ST2_7_6 = 0.00;
I2_7_6 = 0.0;
Alfa2_7_6 = 0.000066;
A2_7 = 1000;
Beta2_7_6= 0.000011;
! Equations for tributary 2 (El Khais), Reach 7 (Qaliobiya), June;
T2_7_6 = SU2_7_6 + ST2_7_6 + I2_7_6 + D2_7_6 - U2_7_6;
D2_7_6 = Alfa2_7_6*A2_7;
```

```
U2_7_6 = Beta2_7_6*A2_7;

 !Data for tributary 3 (El Asloogy), Reach 7(Qaliobiya), June;
SU3_7_6 = 0.00;
ST3_7_6 = 1.44;
I3_7_6 = 0.0;
Alfa3_7_6 = 0.000066;
A3_7 = 5300;
Beta3_7_6= 0.000011;
! Equations for tributary 3 (El Asloogy), Reach 7 (Qaliobiya), June;
T3_7_6 = SU3_7_6 + ST3_7_6 + I3_7_6 + D3_7_6 - U3_7_6;
D3_7_6 = Alfa3_7_6*A3_7;
U3_7_6 = Beta3_7_6*A3_7;

!Data for Reach 7 (Qaliobiya), June;
P7_6 = 0.0;
L7_6 = 0.0;
I7_6=0.0;
D7_6 = 0.0;
!Equation for Reach 7 (Qaliobiya), June;
Q7_6 = Q6_6 + P7_6 - L7_6 +I7_6+ D7_6 + T1_7_6 + T2_7_6 + T3_7_6;

!Data for tributary 1 (Bourden), Reach 7(Qaliobiya), June;
CSU1_7_6 = 12.5;
CST1_7_6 = 9.5;
CI1_7_6 = 10;
CD1_7_6 = 1.5;
CU1_7_6 - CT1_7_6 = 0;
R1_7_6 = K1_7_6*CT1_7_6;
!K1_7_6 = 0.28/86400;
V1_7_6 = 11002;
! Equations for tributary 1 (Bourden), Reach 7 (Qaliobiya), June;
T1_7_6*CT1_7_6 = SU1_7_6* CSU1_7_6 + ST1_7_6*CST1_7_6+ I1_7_6*CI1_7_6
+ D1_7_6*CD1_7_6 - U1_7_6*CU1_7_6 - R1_7_6*V1_7_6;

!Data for tributary 2 (El Khais), Reach 7(Qaliobiya), June;
CSU2_7_6 = 12.5;
CST2_7_6 = 9.5;
CI2_7_6 = 10;
CD2_7_6 = 1.5;
CU2_7_6 - CT2_7_6 = 0;
R2_7_6 = K2_7_6*CT2_7_6;
!K2_7_6 = 0.28/86400;
V2_7_6 = 359;
! Equations for tributary 2 (El Khais), Reach 7 (Qaliobiya), June;
T2_7_6*CT2_7_6 = SU2_7_6* CSU2_7_6 + ST2_7_6*CST2_7_6+ I2_7_6*CI2_7_6
+ D2_7_6*CD2_7_6 - U2_7_6*CU2_7_6 - R2_7_6*V2_7_6;

!Data for tributary 3 (El Asloogy), Reach 7(Qaliobiya), June;
!KT3_7_6 = 0.28/86400;
Tau3_7_6= 0.42;
Cin3_7_6 = 9.5;
CT3_7_6- Cin3_7_6*(@exp(-kT3_7_6*Tau3_7_6)) =0;
```

```
! Data for Reach 7 (Qaliobiya), June;
CP7_6 = 1;
CL7_6 = 1;
CI7_6=10;
CD7_6=1.5;
RQ7_6=KQ7_6*C7_6;
!KQ7_6=0.28/86400;
VQ7_6=313406;
!Equation for Reach 7 (Qaliobiya), June;
Q7_6*C7_6 = Q6_6*C6_6 + P7_6*CP7_6+I7_6*CI7_6 - L7_6*CL7_6 +
D7_6*CD7_6-RQ7_6*VQ7_6 + T1_7_6*CT1_7_6 + T2_7_6*CT2_7_6 +
T3_7_6*CT3_7_6;

!Data for tributary 1 (South belbeis), Reach 8(belbeis), June;
!SU1_8_6 = 0.25;
!ST1_8_6 = 0.0;
!I1_8_6 = 0.0;
!Alfa1_8_6 = 0.000173;
!A1_8 = 4600;
!Beta1_8_6= 0.00;
!Equations for tributary 1 (South belbeis), Reach 8(belbeis), June;
!T1_8_6 = SU1_8_6 + ST1_8_6 + I1_8_6 + D1_8_6 - U1_8_6;
!D1_8_6 = Alfa1_8_6*A1_8;
!U1_8_6 = Beta1_8_6*A1_8;

!Data for tributary 2 (El Berka), Reach 8(belbeis), June;
!SU2_8_6 = 0.25;
!ST2_8_6 = 0.00;
!I2_8_6 = 0.00;
!Alfa2_8_6 = 0.000173;
!A2_8 = 2300;
!Beta2_8_6= 0.00;
!Equations for tributary 2 (El Berka), Reach 8(belbeis), June;
!T2_8_6 = SU2_8_6 + ST2_8_6 + I2_8_6 + D2_8_6 - U2_8_6;
!D2_8_6 = Alfa2_8_6*A2_8;
!U2_8_6 = Beta2_8_6*A2_8;

!Data for tributary 3 (El Khosous)Reach 8(belbeis), June;
!SU3_8_6 = 0.5;
!ST3_8_6 = 0.00;
!I3_8_6 = 0.00;
!Alfa3_8_6 = 0.000173;
!A3_8 = 6100;
!Beta3_8_6= 0.00;
!Equations for tributary 3 (El Khosous), Reach 8(belbeis), June;
!T3_8_6 = SU3_8_6 + ST3_8_6 + I3_8_6 + D3_8_6 - U3_8_6;
!D3_8_6 = Alfa3_8_6*A3_8;
!U3_8_6 = Beta3_8_6*A3_8;

!Data for Reach 8 (Belbeis), June;
!Qb_6 = 0.0;
!P8_6 = 0.0;
!L8_6 = 0.0;
```

```
!I8_6=0.00;
!DAG8_6 = 0.0;
!DSA8_6 = 0.116; ! Sariakous WWTP;
!Equation for Reach 8 (Belbeis), June;
!Q8_6 = Qb_6 + P8_6 - L8_6+I8_6 + DAG8_6 + DSA8_6  + T1_8_6 + T2_8_6 +
T3_8_6;

! Data for tributary 1 (South belbeis), Reach 8(belbeis), June;
!CSU1_8_6 = 12.5;
!CST1_8_6 = 9.5;
!CD1_8_6=1.5;
!TauM1_8_6=0.32;
!K1_8_6=0.28/86400;
!CM1_8_6* (SU1_8_6+ D1_8_6) = SU1_8_6 *CSU1_8_6 +D1_8_6*CD1_8_6;
!CT1_8_6*K1_8_6=(CM1_8_6/TauM1_8_6)*(1-@exp(-K1_8_6*TauM1_8_6));
!CT1_8_6= CM1_8_6*(@exp(-K1_8_6*TauM1_8_6));

!Data for tributary 2 (El Berka), Reach 8(belbeis), June;
!CSU2_8_6 = 12.5;
!CST2_8_6 = 9.5;
!CD2_8_6=1.5;
!TauM2_8_6=0.5;
!K2_8_6=0.28/86400;
!CM2_8_6* (SU2_8_6+ D2_8_6) = SU2_8_6 *CSU2_8_6 +D2_8_6*CD2_8_6;
!CT2_8_6*K2_8_6=(CM2_8_6/TauM2_8_6)*(1-@exp(-K2_8_6*TauM2_8_6));
!CT2_8_6= CM2_8_6*(@exp(-K2_8_6*TauM2_8_6));
!CT2_8_6= 1.49;

!Data for tributary 3 (El Khosous)Reach 8(belbeis), June;
!CSU3_8_6 = 12.5;
!CST3_8_6 = 9.5;
!CD3_8_6=1.5;
!TauM3_8_6=0.57;
!K3_8_6=0.28/86400;
!CM3_8_6* (SU3_8_6+ D3_8_6) = SU3_8_6 *CSU3_8_6 +D3_8_6*CD3_8_6;
!CT3_8_6*K3_8_6=(CM3_8_6/TauM3_8_6)*(1-@exp(-K3_8_6*TauM3_8_6));
!CT3_8_6= CM3_8_6*(@exp(-K3_8_6*TauM3_8_6));

!Data for Reach 8 (Belbeis), June;
!Cin8_6*(T1_8_6+T2_8_6+T3_8_6)=((T1_8_6*CT1_8_6)+(T2_8_6*CT2_8_6)+(T3_
8_6*CT3_8_6));
!!KB8_6=0.28/86400;
!Tau8_6=0.26;
!C8_6-Cin8_6*(@exp(-KB8_6*Tau8_6))=0;

!for Belbeis drain, we are starting the system at EB14

since we have measured data at that point.  1999/2000 data is
being used for the flowrate.  2004/2005 data is being used for
the concentration;

Q8_6 = 5.05;
C8_6 = 1.20;
```

```
!Data for tributary 1 (El Gabal El Asfar ), Reach 9(Belbeis), June;
SU1_9_6 =0.0;
ST1_9_6 = 23.15;
I1_9_6 = 0.0;
Alfa1_9_6 = 0.000066;
A1_9 = 7000;
Beta1_9_6= 0.000011;
!Equations for tributary 1 (El Gabal El Asfar), Reach 9(Belbeis),
June;
T1_9_6 = SU1_9_6 + ST1_9_6 + I1_9_6 + D1_9_6 - U1_9_6;
D1_9_6 = Alfa1_9_6*A1_9;
U1_9_6 = Beta1_9_6*A1_9;

!Data for tributary 2 (El Anaber), Reach 9(Belbeis), June;
SU2_9_6 = 0.00;
ST2_9_6 = 0.11;
I2_9_6 = 0.00;
Alfa2_9_6 = 0.000066;
A2_9 = 1900;
Beta2_9_6= 0.000011;
!Equations for tributary 2 (El Anaber), Reach 9(Belbeis), June;
T2_9_6 = SU2_9_6 + ST2_9_6 + I2_9_6 + D2_9_6 - U2_9_6;
D2_9_6 = Alfa2_9_6*A2_9;
U2_9_6 = Beta2_9_6*A2_9;

!Data for Reach 9 (Belbeis), June;
P9_6 = 0.0;
L9_6 = 0.0;
I9_6=0.00;
DAG9_6 = 0.00;
DSA9_6 = 0.138; ! Shebeen El Kanater WWTP;
!Equation for Reach 2 (Belbeis), June;
Q9_6 = Q8_6 + P9_6 - L9_6+I9_6 + DAG9_6 + DSA9_6  + T1_9_6 + T2_9_6;

!Data for tributary 1 (El Gabal El Asfar ), Reach 9(Belbeis), June;
!KT1_9_6 = 0.28/86400;
Tau1_9_6= 0.18;
Cin1_9_6 = 9.5;
CT1_9_6- Cin1_9_6*(@exp(-kT1_9_6*Tau1_9_6)) =0;

!Data for tributary 2 (El Anaber), Reach 9(Belbeis), June;
CSU2_9_6 = 12.5;
CST2_9_6 = 9.5;
CI2_9_6 = 10;
CD2_9_6 = 1.5;
CU2_9_6 - CT2_9_6 = 0;
R2_9_6 = K2_9_6*CT2_9_6;
!K2_9_6 = 0.28/86400;
V2_9_6 = 4320;
!Equations for tributary 2 (El Anaber), Reach 9(Belbeis), June;
T2_9_6*CT2_9_6 = SU2_9_6* CSU2_9_6 + ST2_9_6*CST2_9_6+ I2_9_6*CI2_9_6
+ D2_9_6*CD2_9_6 - U2_9_6*CU2_9_6 - R2_9_6*V2_9_6;
```

```
!Data for Reach 9 (Belbeis), June;
CP9_6 = 1;
CL9_6 = 1;
CI9_6=10;
CDAG9_6=1.5;
CDSA9_6=9.5;
RB9_6=KB9_6*C9_6;
!KB9_6=0.28/86400;
VB9_6=875088;
!Equation for Reach 9 (Belbeis), June;
Q9_6*C9_6 = Q8_6*C8_6 + P9_6*CP9_6 - L9_6*CL9_6+I9_6*CI9_6 +
DAG9_6*CDAG9_6 + DSA9_6*CDSA9_6-RB9_6*VB9_6 +
T1_9_6*CT1_9_6+T2_9_6*CT2_9_6;

!Data for tributary 1 (Enshas & Sholyah), Reach 10(Belbeis), June;
SU1_10_6 = 0.00;
ST1_10_6 = 0.00;
I1_10_6 = 0.00;
Alfa1_10_6 = 0.000066;
A1_10 = 9600;
Beta1_10_6= 0.000011;
!Equations for tributary 1 (Enshas & Sholyah), Reach 10(Belbeis),
June;
T1_10_6 = SU1_10_6 + ST1_10_6 + I1_10_6 + D1_10_6 - U1_10_6;
D1_10_6 = Alfa1_10_6*A1_10;
U1_10_6 = Beta1_10_6*A1_10;

!Data for tributary 2 (Snaikah), Reach 10(Belbeis), June;
!assuming Alfa2_10_6 = Beta2_10_6;
SU2_10_6 = 0.00;
ST2_10_6 = 0.00;
I2_10_6 = 0.00;
Alfa2_10_6 = 0.000066;
A2_10 = 16000;
Beta2_10_6= 0.000066;
!Equations for tributary 2 (Snaikah), Reach 10(Belbeis), June;
T2_10_6 = SU2_10_6 + ST2_10_6 + I2_10_6 + D2_10_6 - U2_10_6;
D2_10_6 = Alfa2_10_6*A2_10;
U2_10_6 = Beta2_10_6*A2_10;

!Data for Reach 10 (Belbeis), June;
P10_6 = 0.0;
L10_6 = 0.0;
I10_6 = 0.00;
DAG10_6 =0.00;
DSA10_6 = 0.463;
!Equation for Reach 10 (Belbeis), June;
Q10_6 = Q9_6 + P10_6 - L10_6 + I10_6 + DAG10_6+ DSA10_6 + T1_10_6 +
T2_10_6 ;

!Data for tributary 1 (Enshas & Sholyah), Reach 10(Belbeis), June;
CSU1_10_6 =12.5;
```

```
CST1_10_6 = 9.5;
CI1_10_6 = 10;
CD1_10_6 = 1.5;
CU1_10_6 - CT1_10_6 = 0;
R1_10_6 = K1_10_6*CT1_10_6;
!K1_10_6 = 0.28/86400;
V1_10_6 = 13707;
!Equations for tributary 1 (Enshas & Sholyah), Reach 10 (Belbeis),
June;
T1_10_6*CT1_10_6 = SU1_10_6* CSU1_10_6 + ST1_10_6*CST1_10_6+
I1_10_6*CI1_10_6 + D1_10_6*CD1_10_6 - U1_10_6*CU1_10_6 -
R1_10_6*V1_10_6;

!Data for tributary 2 (Snaikah), Reach 10(Belbeis), June;
CSU2_10_6 =12.5;
CST2_10_6 = 9.5;
CI2_10_6 = 10;
CD2_10_6 = 1.5;
CU2_10_6 - CT2_10_6 = 0;
R2_10_6 = K2_10_6*CT2_10_6;
!K2_10_6 = 0.28/86400;
V2_10_6 = 15557;
!Equations for tributary 2 (Snaikah), Reach 10 (Belbeis), June;
T2_10_6*CT2_10_6 = SU2_10_6* CSU2_10_6 + ST2_10_6*CST2_10_6+
I2_10_6*CI2_10_6 + D2_10_6*CD2_10_6 - U2_10_6*CU2_10_6 -
R2_10_6*V2_10_6;

!Data for Reach 10 (Belbeis), June;
CP10_6 = 1;
CL10_6 = 1;
CI10_6=10;
RB10_6=KB10_6*C10_6;
!KB10_6=0.28/86400;
VB10_6=1338120;
CDAG10_6=1.5;
CDSA10_6=9.5;

!Equation for Reach 10 (Belbeis), June;
Q10_6*C10_6 = Q9_6*C9_6 + P10_6*CP10_6+I10_6*CI10_6 - L10_6*CL10_6 +
DAG10_6*CDAG10_6+DSA10_6*CDSA10_6 -RB10_6*VB10_6 + T1_10_6*CT1_10_6 ;

!Data for tributary 1 (Bany Goray), Reach 11(Bahr El Baqar), June;
SU1_11_6 = 0.0;
ST1_11_6 = 0.0;
I1_11_6 = 0.0;
Alfa1_11_6 = 0.000066;
A1_11 = 1500;
Beta1_11_6= 0.000011;
!Equations for tributary 1 (Bany Goray), Reach 11(Bahr El Baqar),
June;
T1_11_6 = SU1_11_6 + ST1_11_6 + I1_11_6 + D1_11_6 - U1_11_6;
D1_11_6 = Alfa1_11_6*A1_11;
U1_11_6 = Beta1_11_6*A1_11;
```

```
!Data for tributary 2 (Twaher), Reach 11(Bahr El Baqar), June;
SU2_11_6 = 0.00;
ST2_11_6 = 0.00;
I2_11_6 = 0.00;
Alfa2_11_6 = 0.000066;
A2_11 = 3000;
Beta2_11_6= 0.000011;
!Equations for tributary 2 (Twaher), Reach 11(Bahr El Baqar), June;
T2_11_6 = SU2_11_6 + ST2_11_6 + I2_11_6 + D2_11_6 - U2_11_6;
D2_11_6 = Alfa2_11_6*A2_11;
U2_11_6 = Beta2_11_6*A2_11;

!Data for tributary 3 (El Azazy), Reach 11(Bahr El Baqar), June;
SU3_11_6 = 0.00;
ST3_11_6 = 0.00;
I3_11_6 = 0.00;
Alfa3_11_6 = 0.000066;
A3_11 = 31000;
Beta3_11_6= 0.000011;
!Equations for tributary 3 (El Azazy), Reach 11(Bahr El Baqar), June;
T3_11_6 = SU3_11_6 + ST3_11_6 + I3_11_6 + D3_11_6 - U3_11_6;
D3_11_6 = Alfa3_11_6*A3_11;
U3_11_6 = Beta3_11_6*A3_11;

!Data for Reach 11 (Bahr El Baqar), June;
!QT_6 means Q Total end of Qalyobia (Q7_6)+ Q end of Belbeis (Q10_6);
QT_6 = Q7_6+Q10_6;
P11_6 = 0.0;
L11_6 = 0.0;
I11_6=0.00;
D11_6 = 0.39;

!Equation for Reach 11 (Bahr El Baqar), June;
Q11_6 = QT_6 + P11_6 - L11_6 + D11_6+I11_6 + T1_11_6 + T2_11_6 +
T3_11_6;

!Data for tributary 1 (Bany Goray), Reach 11(Bahr El Baqar), June;
CSU1_11_6 = 12.5;
CST1_11_6 = 9.5;
CI1_11_6 = 10;
CD1_11_6 = 1.5;
CU1_11_6 - CT1_11_6 = 0;
R1_11_6 = K1_11_6*CT1_11_6;
!K1_11_6 = 0.28/86400;
V1_11_6 = 1824;
!Equations for tributary 1 (Bany Goray), Reach 11(Bahr El Baqar),
June;
T1_11_6*CT1_11_6 = SU1_11_6* CSU1_11_6 + ST1_11_6*CST1_11_6+
I1_11_6*CI1_11_6 + D1_11_6*CD1_11_6 - U1_11_6*CU1_11_6 -
R1_11_6*V1_11_6;

!Data for tributary 2 (Twaher), Reach 11(Bahr El Baqar), June;
```

```
CSU2_11_6 = 12.5;
CST2_11_6 = 9.5;
CI2_11_6 = 10;
CD2_11_6 = 1.5;
CU2_11_6 - CT2_11_6 = 0;
R2_11_6 = K2_11_6*CT2_11_6;
!K2_11_6 = 0.28/86400;
V2_11_6 = 4674;
!Equations for tributary 2 (Twaher), Reach 11(Bahr El Baqar), June;
T2_11_6*CT2_11_6 = SU2_11_6* CSU2_11_6 + ST2_11_6*CST2_11_6+
I2_11_6*CI2_11_6 + D2_11_6*CD2_11_6 - U2_11_6*CU2_11_6 -
R2_11_6*V2_11_6;

!Data for tributary 3 (El Azazy), Reach 11(Bahr El Baqar), June;
CSU3_11_6 = 12.5;
CST3_11_6 = 9.5;
CI3_11_6 = 10;
CD3_11_6 = 1.5;
CU3_11_6 - CT3_11_6 = 0;
R3_11_6 = K3_11_6*CT3_11_6;
!K3_11_6 = 0.28/86400;
V3_11_6 = 60822;
!Equations for tributary 3 (El Azazy), Reach 11(Bahr El Baqar), June;
T3_11_6*CT3_11_6 = SU3_11_6* CSU3_11_6 + ST3_11_6*CST3_11_6+
I3_11_6*CI3_11_6 + D3_11_6*CD3_11_6 - U3_11_6*CU3_11_6 -
R3_11_6*V3_11_6;

!Data for Reach 11 (Bahr El Baqar), June;
CT_6 = (Q7_6*C7_6+Q10_6*C10_6) /(Q7_6+Q10_6);
CP11_6 = 1;
CL11_6 = 1;
CD11_6=1.5;
CI11_6=10;
RR11_6=KR11_6*C11_6;
!KR11_6=0.28/86400;
VR11_6=905301;

!Equation for Reach 11 (Bahr El Baqar), June;
Q11_6*C11_6 = QT_6*CT_6 + P11_6*CP11_6 - L11_6*CL11_6 +I11_6*CI11_6+
D11_6*CD11_6-RR11_6*VR11_6 + T1_11_6*CT1_11_6 + T2_11_6*CT2_11_6 +
T3_11_6*CT3_11_6;

!Data for tributary 1 (El Haramy), Reach 12(Bahr El Baqar), June;
SU1_12_6 = 0.00;
ST1_12_6 = 0.231;
I1_12_6 = 0.0;
Alfa1_12_6 = 0.000066;
A1_12 = 11500;
Beta1_12_6= 0.000023;
!Equations for tributary 1 (El Haramy), Reach 12(Bahr El Baqar), June;
T1_12_6 = SU1_12_6 + ST1_12_6 + I1_12_6 + D1_12_6 - U1_12_6;
D1_12_6 = Alfa1_12_6*A1_12;
U1_12_6 = Beta1_12_6*A1_12;
```

```
!Data for tributary 2 (El Manaher), Reach 12(Bahr El Baqar), June;
SU2_12_6 = 0.00;
ST2_12_6 = 0.00;
I2_12_6 = 0.00;
Alfa2_12_6 = 0.000066;
A2_12 = 2000;
Beta2_12_6= 0.000023;
!Equations for tributary 2 (El Manaher), Reach 12(Bahr El Baqar),
June;
T2_12_6 = SU2_12_6 + ST2_12_6 + I2_12_6 + D2_12_6 - U2_12_6;
D2_12_6 = Alfa2_12_6*A2_12;
U2_12_6 = Beta2_12_6*A2_12;

!Data for tributary 3 (El Bateekh), Reach 12(Bahr El Baqar), June;
SU3_12_6 = 0.00;
ST3_12_6 = 0.00;
I3_12_6 = 0.00;
Alfa3_12_6 = 0.000066;
A3_12 = 6000;
Beta3_12_6= 0.000023;
!Equations for tributary 3 (El Bateekh), Reach 12(Bahr El Baqar),
June;
T3_12_6 = SU3_12_6 + ST3_12_6 + I3_12_6 + D3_12_6 - U3_12_6;
D3_12_6 = Alfa3_12_6*A3_12;
U3_12_6 = Beta3_12_6*A3_12;

!Data for Reach 12 (Bahr El Baqar), June;
P12_6 = 0.0;
L12_6 = 0.0;
I12_6=0.00;
DAG12_6 = 0.597;
DSA12_6 = 0.231; !El Fakous WWTP;
!Equation for Reach 12 (Bahr El Baqar), June;
Q12_6 = Q11_6 + P12_6 - L12_6+I12_6 + DAG12_6 + DSA12_6 + T1_12_6 +
T2_12_6 + T3_12_6 ;

!Data for tributary 1 (El Haramy), Reach 12(Bahr El Baqar), June;
CSU1_12_6 = 12.5;
CST1_12_6 = 9.5;
CI1_12_6 = 10;
CD1_12_6 = 1.5;
CU1_12_6 - CT1_12_6 = 0;
R1_12_6 = K1_12_6*CT1_12_6;
!K1_12_6 = 0.28/86400;
V1_12_6 = 19492;

! Equations for tributary 1 (El Haramy), Reach 12(Bahr El Baqar),
June;
T1_12_6*CT1_12_6 = SU1_12_6* CSU1_12_6 + ST1_12_6*CST1_12_6+
I1_12_6*CI1_12_6 + D1_12_6*CD1_12_6 - U1_12_6*CU1_12_6 -
R1_12_6*V1_12_6;
```

```
!Data for tributary 2 (El Manaher), Reach 12(Bahr El Baqar), June;
CSU2_12_6 = 12.5;
CST2_12_6 = 9.5;
CI2_12_6 = 10;
CD2_12_6 = 1.5;
CU2_12_6 - CT2_12_6 = 0;
R2_12_6 = K2_12_6*CT2_12_6;
!K2_12_6 = 0.28/86400;
V2_12_6 = 2451;
!Equations for tributary 2 (El Manaher), Reach 12(Bahr El Baqar),
June;
T2_12_6*CT2_12_6 = SU2_12_6* CSU2_12_6 + ST2_12_6*CST2_12_6+
I2_12_6*CI2_12_6 + D2_12_6*CD2_12_6 - U2_12_6*CU2_12_6 -
R2_12_6*V2_12_6;

!Data for tributary 3 (El Bateekh), Reach 12(Bahr El Baqar), June;
CSU3_12_6 = 12.5;
CST3_12_6 = 9.5;
CI3_12_6 = 10;
CD3_12_6 = 1.5;
CU3_12_6 - CT3_12_6 = 0;
R3_12_6 = K3_12_6*CT3_12_6;
!K3_12_6 = 0.28/86400;
V3_12_6 = 6372;
!Equations for tributary 3 (El Bateekh), Reach 12(Bahr El Baqar),
June;
T3_12_6*CT3_12_6 = SU3_12_6* CSU3_12_6 + ST3_12_6*CST3_12_6+
I3_12_6*CI3_12_6 + D3_12_6*CD3_12_6 - U3_12_6*CU3_12_6 -
R3_12_6*V3_12_6;

!Data for Reach 12 (Bahr El Baqar), June;
CP12_6 = 1;
CL12_6 = 1;
CI12_6=10;
CDAG12_6=1.5;
CDSA12_6=9.5;
RR12_6=KR12_6*C12_6;
!KR12_6=0.28/86400;
VR12_6=1137931;
!Equation for Reach 12 (Bahr El Baqar), June;
Q12_6*C12_6 = Q11_6*C11_6 + P12_6*CP12_6 - L12_6*CL12_6 + I12_6
*CI12_6 + DAG12_6*CDAG12_6+ DSA12_6*CDSA12_6-RR12_6*VR12_6 +
T1_12_6*CT1_12_6 + T2_12_6*CT2_12_6 + T3_12_6*CT3_12_6 ;

!Data for tributary 1 (El Saada Drainage P.S), Reach 13(Bahr El
baqar), June;
SU1_13_6 = 0.00;
ST1_13_6 = 0.00;
I1_13_6 = 0.0;
Alfa1_13_6 = 0.000066;
A1_13 = 17000;
Beta1_13_6= 0.000023;
```

```
!Equations for tributary 1 (El Saada Drainage P.S), Reach 13(Bahr El
baqar), June;
T1_13_6 = SU1_13_6 + ST1_13_6 + I1_13_6 + D1_13_6 - U1_13_6;
D1_13_6 = Alfa1_13_6*A1_13;
U1_13_6 = Beta1_13_6*A1_13;

!Data for tributary 2 (Abou Taleb Drain), Reach 13(Bahr El baqar),
June;
SU2_13_6 = 0.00;
ST2_13_6 = 0.00;
I2_13_6 = 0.0;
Alfa2_13_6 = 0.000066;
A2_13 = 10100;
Beta2_13_6= 0.000023;
!Equations for tributary 2 (Abou Taleb Drain), Reach 13(Bahr El
baqar), June;
T2_13_6 = SU2_13_6 + ST2_13_6 + I2_13_6 + D2_13_6 - U2_13_6;
D2_13_6 = Alfa2_13_6*A2_13;
U2_13_6 = Beta2_13_6*A2_13;

!Data for Reach 13 (Bahr El baqar), June;
P13_6 = 0.0;
L13_6 = 0.0;
D13_6 = 0.465;
I13_6=0.00;
!Equation for Reach 13 (Bahr El baqar), June;
Q13_6 = Q12_6 + P13_6 - L13_6 + D13_6 + I13_6 + T1_13_6 + T2_13_6;

!Data for tributary 1 (El Saada Drainage P.S), Reach 13(Bahr El
baqar), June;
!CT1_13_6=9;
CT1_13_6=0.22;

! Data for tributary 2 (Abou Taleb Drain), Reach 13(Bahr El baqar),
June;
CSU2_13_6 = 12.5;
CST2_13_6 = 9.5;
CI2_13_6 = 10;
CD2_13_6 = 1.5;
CU2_13_6 - CT2_13_6 = 0;
R2_13_6 = K2_13_6*CT2_13_6;
!K2_13_6 = 0.28/86400;
V2_13_6 = 14709;
! Equations for tributary 2 (Abou Taleb Drain), Reach 13(Bahr El
baqar), June;
T2_13_6*CT2_13_6 = SU2_13_6* CSU2_13_6 + ST2_13_6*CST2_13_6+
I2_13_6*CI2_13_6 + D2_13_6*CD2_13_6 - U2_13_6*CU2_13_6 -
R2_13_6*V2_13_6;

!Data for Reach 13 (Bahr El baqar), June;
CP13_6 = 1;
CL13_6 = 1;
CD13_6=1.5;
```

```
CI13_6=10.00;
RR13_6=KR13_6*C13_6;
!KR13_6=0.28/86400;
VR13_6=1792928;

!Equation for Reach 13 (Bahr El Baqar), June;
Q13_6*C13_6 = Q12_6*C12_6 + P13_6*CP13_6 - L13_6*CL13_6 + I13_6 *
CI13_6 + D13_6*CD13_6-RR13_6*VR13_6 + T1_13_6*CT1_13_6 +
T2_13_6*CT2_13_6;

!Data for tributary 1 (Qahbonah D.P.S), Reach 14(Bahr El Baqar), June;
SU1_14_6 = 0.00;
ST1_14_6 = 0.00;
I1_14_6 = 0.0;
Alfa1_14_6 = 0.000066;
A1_14 = 17000;
Beta1_14_6= 0.000023;
!Equations for tributary 1 (Qahbonah D.P.S), Reach 14 (Bahr El Baqar),
June;
T1_14_6 = SU1_14_6 + ST1_14_6 + I1_14_6 + D1_14_6 - U1_14_6;
D1_14_6 = Alfa1_14_6*A1_14;
U1_14_6 = Beta1_14_6*A1_14;

!Data for tributary 2 (Bahr El baqar D.P.S), Reach 14(Bahr El baqar),
June;
SU2_14_6 = 0.00;
ST2_14_6 = 0.00;
I2_14_6 = 0.0;
Alfa2_14_6 = 0.000066;
A2_14 = 47000;
Beta2_14_6= 0.000023;
!Equations for tributary 2 (Bahr El baqar D.P.S), Reach 14 (Bahr El
baqar), June;
T2_14_6 = SU2_14_6 + ST2_14_6 + I2_14_6 + D2_14_6 - U2_14_6;
D2_14_6 = Alfa2_14_6*A2_14;
U2_14_6 = Beta2_14_6*A2_14;

!Data for Reach 14 (Bahr El baqar), June;
P14_6 = 0.0;
L14_6 = 0.0;
I14_6 = 0.00;
DAG14_6 = 0.05576;
DSA14_6 = 0.230;
R14_6  =2.06;
!Equation for Reach 14 (Bahr El baqar), June;
Q14_6 = Q13_6 + P14_6 - L14_6 + I14_6 + DAG14_6 +DSA14_6 - R14_6 +
T1_14_6 + T2_14_6;

!Data for tributary 1 (Qahbonah D.P.S), Reach 14(Bahr El Baqar), June;
CT1_14_6= 0.95;

!Data for tributary 2 (Bahr El baqar D.P.S), Reach 14(Bahr El baqar),
June;
```

```
CT2_14_6=0.5;

!Data for Reach 14 (Bahr El baqar), June;
CP14_6 = 1;
CL14_6 = 1;
CI14_6=10;
Cdag14_6=1.5;
CDsa14_6=9.5;
C14_6-CR14_6=0;
RR14_6=KR14_6*C14_6;
!KR14_6=0.28/86400;
VR14_6=2520704;
!Equation for Reach 14 (Bahr El Baqar), June;
Q14_6*C14_6 = Q13_6*C13_6 + P14_6*CP14_6 +I14_6*CI14_6 - L14_6*CL14_6-
R14_6*CR14_6-RR14_6*VR14_6 + Dag14_6*Cdag14_6 + Dsa14_6*CDsa14_6
+T1_14_6*CT1_14_6 + T2_14_6*CT2_14_6;

!Data for tributary 1 (South Port Saeed D.P.S), Reach 15(Bahr El Baqar
drain), June;
SU1_15_6 = 0.00;
ST1_15_6 = 0.00;
I1_15_6 = 0.0;
Alfa1_15_6 = 0.000066;
A1_15 = 47320;
Beta1_15_6= 0.000023;
! Equations for tributary 1 (South Port Saeed D.P.S), Reach 15 (Bahr
El Baqar drain), June;
T1_15_6 = SU1_15_6 + ST1_15_6 + I1_15_6 + D1_15_6 - U1_15_6;
D1_15_6 = Alfa1_15_6*A1_15;
U1_15_6 = Beta1_15_6*A1_15;

!Data for tributary 2 (South Sahl El Husanayah D.P.S), Reach 15(Bahr
El Baqar drain), June;
SU2_15_6 = 0.00;
ST2_15_6 = 0.00;
I2_15_6 = 0.0;
Alfa2_15_6 = 0.000066;
A2_15 = 57500;
Beta2_15_6= 0.000023;
!Equations for tributary 2 (South Sahl El Husanayah D.P.S), Reach 15
(Bahr El Baqar drain), June;
T2_15_6 = SU2_15_6 + ST2_15_6 + I2_15_6 + D2_15_6 - U2_15_6;
D2_15_6 = Alfa2_15_6*A2_15;
U2_15_6 = Beta2_15_6*A2_15;

 !Data for Reach 15 (Bahr El Baqar drain), June;
P15_6 = 0.0;
L15_6 = 0.0;
I15_6=0.00;
D15_6 = 0.00;
!Equation for Reach 15 (Bahr El Baqar drain), June;
Q15_6 = Q14_6 + P15_6 - L15_6  + I15_6 + D15_6 + T1_15_6 + T2_15_6;
```

```
!Data for tributary 1 (South Port Saeed D.P.S), Reach 15(Bahr El Baqar
drain), June;
CT1_15_6=0.95;

!Data for tributary 2 (South Sahl El Husanayah D.P.S), Reach 15(Bahr
El Baqar drain), June;
CT2_15_6= 0.95;

!Data for Reach 15 (Bahr El Baqar drain), June;
CP15_6 = 1;
CL15_6 = 1;
CI15_6=10;
CD15_6=1.5;
RR15_6=KR15_6*C15_6;
!KR15_6=0.28/86400;
VR15_6=547338;
!Equation for Reach 15 (Bahr El Baqar), June;
Q15_6*C15_6 = Q14_6*C14_6 + P15_6*CP15_6 - L15_6*CL15_6 + I15_6*CI15_6
+  D15_6*CD15_6-RR15_6*VR15_6+ T1_15_6*CT1_15_6 + T2_15_6*CT2_15_6;
```

```
  Global optimal solution found.
  Objective value:                              18.72969
  Total solver iterations:                             0
```

Variable	Value	Reduced Cost
KT1_1_6	0.9041909E-05	0.000000
CPNEW	18.72969	0.000000
QPNEW	2.000000	0.000000
C15_6	1.300000	0.000000
DAILY_INITIAL_LOAD	2160.000	0.000000
COST4	9748704.	0.000000
K2_1_6	0.9041909E-05	0.000000
K3_1_6	0.9041909E-05	0.000000
K4_1_6	0.9041909E-05	0.000000
K5_1_6	0.9041909E-05	0.000000
K1_2_6	0.9041909E-05	0.000000
K2_2_6	0.9041909E-05	0.000000
K3_2_6	0.9041909E-05	0.000000
K1_3_6	0.9041909E-05	0.000000
K2_3_6	0.9041909E-05	0.000000
K3_3_6	0.9041909E-05	0.000000
K4_3_6	0.9041909E-05	0.000000
K1_4_6	0.9041909E-05	0.000000
K2_4_6	0.9041909E-05	0.000000
K3_4_6	0.9041909E-05	0.000000
K4_4_6	0.9041909E-05	0.000000
K5_4_6	0.9041909E-05	0.000000
K6_4_6	0.9041909E-05	0.000000
K1_5_6	0.9041909E-05	0.000000
K2_5_6	0.9041909E-05	0.000000
K3_5_6	0.9041909E-05	0.000000
K4_5_6	0.9041909E-05	0.000000
K5_5_6	0.9041909E-05	0.000000

K1_6_6	0.9041909E-05	0.000000
K2_6_6	0.9041909E-05	0.000000
K3_6_6	0.9041909E-05	0.000000
K4_6_6	0.9041909E-05	0.000000
K1_7_6	0.9041909E-05	0.000000
K2_7_6	0.9041909E-05	0.000000
KT3_7_6	0.9041909E-05	0.000000
K1_8_6	0.9041909E-05	0.000000
K2_8_6	0.9041909E-05	0.000000
K3_8_6	0.9041909E-05	0.000000
KT1_9_6	0.9041909E-05	0.000000
K2_9_6	0.9041909E-05	0.000000
K1_10_6	0.9041909E-05	0.000000
K2_10_6	0.9041909E-05	0.000000
K1_11_6	0.9041909E-05	0.000000
K2_11_6	0.9041909E-05	0.000000
K3_11_6	0.9041909E-05	0.000000
K1_12_6	0.9041909E-05	0.000000
K2_12_6	0.9041909E-05	0.000000
K3_12_6	0.9041909E-05	0.000000
K2_13_6	0.9041909E-05	0.000000
KB8_6	0.9041909E-05	0.000000
KB9_6	0.9041909E-05	0.000000
KQ1_6	0.9041909E-05	0.000000
KQ2_6	0.9041909E-05	0.000000
KQ3_6	0.9041909E-05	0.000000
KQ4_6	0.9041909E-05	0.000000
KQ5_6	0.9041909E-05	0.000000
KQ6_6	0.9041909E-05	0.000000
KQ7_6	0.9041909E-05	0.000000
KB10_6	0.9041909E-05	0.000000
KR11_6	0.9041909E-05	0.000000
KR12_6	0.9041909E-05	0.000000
KR13_6	0.9041909E-05	0.000000
KR14_6	0.9041909E-05	0.000000
KR15_6	0.9041909E-05	0.000000
SU1_1_6	0.000000	0.000000
ST1_1_6	1.090000	0.000000
I1_1_6	0.000000	0.000000
ALFA1_1_6	0.6600000E-04	0.000000
A1_1	3650.000	0.000000
BETA1_1_6	0.2300000E-04	0.000000
T1_1_6	1.246950	0.000000
D1_1_6	0.2409000	0.000000
U1_1_6	0.8395000E-01	0.000000
SU2_1_6	0.000000	0.000000
ST2_1_6	0.000000	0.000000
I2_1_6	0.000000	0.000000
ALFA2_1_6	0.6600000E-04	0.000000
A2_1	10200.00	0.000000
BETA2_1_6	0.2300000E-04	0.000000
T2_1_6	0.4386000	0.000000
D2_1_6	0.6732000	0.000000

U2_1_6	0.2346000	0.000000
SU3_1_6	0.000000	0.000000
ST3_1_6	0.000000	0.000000
I3_1_6	0.000000	0.000000
ALFA3_1_6	0.6600000E-04	0.000000
A3_1	2300.000	0.000000
BETA3_1_6	0.2300000E-04	0.000000
T3_1_6	0.9890000E-01	0.000000
D3_1_6	0.1518000	0.000000
U3_1_6	0.5290000E-01	0.000000
SU4_1_6	0.000000	0.000000
ST4_1_6	0.000000	0.000000
I4_1_6	0.000000	0.000000
ALFA4_1_6	0.6600000E-04	0.000000
A4_1	950.0000	0.000000
BETA4_1_6	0.2300000E-04	0.000000
T4_1_6	0.4085000E-01	0.000000
D4_1_6	0.6270000E-01	0.000000
U4_1_6	0.2185000E-01	0.000000
SU5_1_6	0.000000	0.000000
ST5_1_6	0.000000	0.000000
I5_1_6	0.000000	0.000000
ALFA5_1_6	0.6600000E-04	0.000000
A5_1	9000.000	0.000000
BETA5_1_6	0.2300000E-04	0.000000
T5_1_6	0.3870000	0.000000
D5_1_6	0.5940000	0.000000
U5_1_6	0.2070000	0.000000
Q0_6	0.6000000	0.000000
P1_6	0.000000	0.000000
L1_6	0.000000	0.000000
I1_6	0.000000	0.000000
D1_6	0.1330000E-01	0.000000
Q1_6	2.825600	0.000000
TAU1_1_6	0.7700000	0.000000
CIN1_1_6	9.500000	0.000000
CT1_1_6	9.499934	0.000000
CSU2_1_6	12.50000	0.000000
CST2_1_6	9.500000	0.000000
CI2_1_6	10.00000	0.000000
CD2_1_6	1.500000	0.000000
CU2_1_6	1.151585	0.000000
CT2_1_6	1.151585	0.000000
R2_1_6	0.1041253E-04	0.000000
V2_1_6	22526.00	0.000000
CSU3_1_6	12.50000	0.000000
CST3_1_6	9.500000	0.000000
CI3_1_6	10.00000	0.000000
CD3_1_6	1.500000	0.000000
CU3_1_6	1.330344	0.000000
CT3_1_6	1.330344	0.000000
R3_1_6	0.1202885E-04	0.000000
V3_1_6	2141.000	0.000000

CSU4_1_6	12.50000	0.000000
CST4_1_6	9.500000	0.000000
CI4_1_6	10.00000	0.000000
CD4_1_6	1.500000	0.000000
CU4_1_6	1.441783	0.000000
CT4_1_6	1.441783	0.000000
R4_1_6	0.1303647E-04	0.000000
V4_1_6	280.0000	0.000000
CSU5_1_6	12.50000	0.000000
CST5_1_6	9.500000	0.000000
CI5_1_6	10.00000	0.000000
CD5_1_6	1.500000	0.000000
CU5_1_6	1.049649	0.000000
CT5_1_6	1.049649	0.000000
R5_1_6	0.9490830E-05	0.000000
V5_1_6	28186.00	0.000000
C0_6	1.000000	0.000000
CP1_6	1.000000	0.000000
CL1_6	1.000000	0.000000
CD1_6	1.500000	0.000000
CI1_6	10.00000	0.000000
RQ1_6	0.3748818E-04	0.000000
C1_6	4.146047	0.000000
VQ1_6	49418.00	0.000000
SU1_2_6	0.000000	0.000000
ST1_2_6	3.470000	0.000000
I1_2_6	1.000000	0.000000
ALFA1_2_6	0.6600000E-04	0.000000
A1_2	40000.00	0.000000
BETA1_2_6	0.2300000E-04	0.000000
T1_2_6	6.190000	0.000000
D1_2_6	2.640000	0.000000
U1_2_6	0.9200000	0.000000
SU2_2_6	0.000000	0.000000
ST2_2_6	0.1100000	0.000000
I2_2_6	0.000000	0.000000
ALFA2_2_6	0.6600000E-04	0.000000
A2_2	1900.000	0.000000
BETA2_2_6	0.2300000E-04	0.000000
T2_2_6	0.1917000	0.000000
D2_2_6	0.1254000	0.000000
U2_2_6	0.4370000E-01	0.000000
SU3_2_6	0.000000	0.000000
ST3_2_6	0.000000	0.000000
I3_2_6	0.000000	0.000000
ALFA3_2_6	0.6600000E-04	0.000000
A3_2	5700.000	0.000000
BETA3_2_6	0.2300000E-04	0.000000
T3_2_6	0.2451000	0.000000
D3_2_6	0.3762000	0.000000
U3_2_6	0.1311000	0.000000
P2_6	0.000000	0.000000
I2_6	0.000000	0.000000

L2_6	0.000000	0.000000
D2_6	0.4970000E-01	0.000000
Q2_6	9.502100	0.000000
TAU1_2_6	1.020000	0.000000
CST1_2_6	9.500000	0.000000
CSU1_2_6	12.50000	0.000000
CD1_2_6	1.500000	0.000000
CI1_2_6	10.00000	0.000000
CU1_2_6	3.177984	0.000000
CT1_2_6	3.177984	0.000000
R1_2_6	0.2873504E-04	0.000000
V1_2_6	498678.0	0.000000
CSU2_2_6	12.50000	0.000000
CST2_2_6	9.500000	0.000000
CI2_2_6	10.00000	0.000000
CD2_2_6	1.500000	0.000000
CU2_2_6	4.625689	0.000000
CT2_2_6	4.625689	0.000000
R2_2_6	0.4182506E-04	0.000000
V2_2_6	3448.000	0.000000
CSU3_2_6	12.50000	0.000000
CST3_2_6	9.500000	0.000000
CI3_2_6	10.00000	0.000000
CD3_2_6	1.500000	0.000000
CU3_2_6	1.150398	0.000000
CT3_2_6	1.150398	0.000000
R3_2_6	0.1040179E-04	0.000000
V3_2_6	12644.00	0.000000
CP2_6	1.000000	0.000000
CL2_6	1.000000	0.000000
CI2_6	10.00000	0.000000
CD2_6	1.500000	0.000000
RQ2_6	0.2611870E-04	0.000000
C2_6	2.888627	0.000000
VQ2_6	198403.0	0.000000
SU1_3_6	0.000000	0.000000
ST1_3_6	0.000000	0.000000
I1_3_6	0.000000	0.000000
ALFA1_3_6	0.6600000E-04	0.000000
A1_3	700.0000	0.000000
BETA1_3_6	0.2300000E-04	0.000000
T1_3_6	0.3010000E-01	0.000000
D1_3_6	0.4620000E-01	0.000000
U1_3_6	0.1610000E-01	0.000000
SU2_3_6	0.000000	0.000000
ST2_3_6	0.8700000	0.000000
I2_3_6	0.000000	0.000000
ALFA2_3_6	0.6600000E-04	0.000000
A2_3	31000.00	0.000000
BETA2_3_6	0.2300000E-04	0.000000
T2_3_6	2.203000	0.000000
D2_3_6	2.046000	0.000000
U2_3_6	0.7130000	0.000000

SU3_3_6	0.000000	0.000000
ST3_3_6	0.000000	0.000000
I3_3_6	0.000000	0.000000
ALFA3_3_6	0.6600000E-04	0.000000
A3_3	2300.000	0.000000
BETA3_3_6	0.2300000E-04	0.000000
T3_3_6	0.9890000E-01	0.000000
D3_3_6	0.1518000	0.000000
U3_3_6	0.5290000E-01	0.000000
SU4_3_6	0.000000	0.000000
ST4_3_6	0.000000	0.000000
I4_3_6	0.000000	0.000000
ALFA4_3_6	0.6600000E-04	0.000000
A4_3	2700.000	0.000000
BETA4_3_6	0.2300000E-04	0.000000
T4_3_6	0.1161000	0.000000
D4_3_6	0.1782000	0.000000
U4_3_6	0.6210000E-01	0.000000
P3_6	0.000000	0.000000
L3_6	0.000000	0.000000
D3_6	0.1330000E-01	0.000000
I3_6	0.000000	0.000000
Q3_6	11.96350	0.000000
CSU1_3_6	12.50000	0.000000
CST1_3_6	9.500000	0.000000
CI1_3_6	10.00000	0.000000
CD1_3_6	1.500000	0.000000
CU1_3_6	1.179390	0.000000
CT1_3_6	1.179390	0.000000
R1_3_6	0.1066393E-04	0.000000
V1_3_6	1389.000	0.000000
CSU2_3_6	12.50000	0.000000
CST2_3_6	9.500000	0.000000
CI2_3_6	10.00000	0.000000
CD2_3_6	1.500000	0.000000
CU2_3_6	2.259642	0.000000
CT2_3_6	2.259642	0.000000
R2_3_6	0.2043148E-04	0.000000
V2_3_6	232234.0	0.000000
CSU3_3_6	12.50000	0.000000
CST3_3_6	9.500000	0.000000
CI3_3_6	10.00000	0.000000
CD3_3_6	1.500000	0.000000
CU3_3_6	1.325443	0.000000
CT3_3_6	1.325443	0.000000
R3_3_6	0.1198453E-04	0.000000
V3_3_6	2211.000	0.000000
CSU4_3_6	12.50000	0.000000
CST4_3_6	9.500000	0.000000
CI4_3_6	10.00000	0.000000
CD4_3_6	1.500000	0.000000
CU4_3_6	1.342265	0.000000
CT4_3_6	1.342265	0.000000

R4_3_6	0.1213663E-04	0.000000
V4_3_6	2316.000	0.000000
CP3_6	1.000000	0.000000
CL3_6	1.000000	0.000000
CI3_6	10.00000	0.000000
CD3_6	1.500000	0.000000
RQ3_6	0.2062715E-04	0.000000
C3_6	2.281282	0.000000
VQ3_6	265488.0	0.000000
SU1_4_6	0.000000	0.000000
ST1_4_6	0.000000	0.000000
I1_4_6	0.000000	0.000000
ALFA1_4_6	0.6600000E-04	0.000000
A1_4	400.0000	0.000000
BETA1_4_6	0.2300000E-04	0.000000
T1_4_6	0.1720000E-01	0.000000
D1_4_6	0.2640000E-01	0.000000
U1_4_6	0.9200000E-02	0.000000
SU2_4_6	0.000000	0.000000
ST2_4_6	0.000000	0.000000
I2_4_6	0.000000	0.000000
ALFA2_4_6	0.6600000E-04	0.000000
A2_4	2600.000	0.000000
BETA2_4_6	0.2300000E-04	0.000000
T2_4_6	0.1118000	0.000000
D2_4_6	0.1716000	0.000000
U2_4_6	0.5980000E-01	0.000000
SU3_4_6	0.000000	0.000000
ST3_4_6	0.000000	0.000000
I3_4_6	0.000000	0.000000
ALFA3_4_6	0.6600000E-04	0.000000
A3_4	18000.00	0.000000
BETA3_4_6	0.2300000E-04	0.000000
T3_4_6	0.7740000	0.000000
D3_4_6	1.188000	0.000000
U3_4_6	0.4140000	0.000000
SU4_4_6	0.000000	0.000000
ST4_4_6	0.000000	0.000000
I4_4_6	0.000000	0.000000
ALFA4_4_6	0.6600000E-04	0.000000
A4_4	3500.000	0.000000
BETA4_4_6	0.2300000E-04	0.000000
T4_4_6	0.1505000	0.000000
D4_4_6	0.2310000	0.000000
U4_4_6	0.8050000E-01	0.000000
SU5_4_6	0.000000	0.000000
ST5_4_6	0.000000	0.000000
I5_4_6	0.000000	0.000000
ALFA5_4_6	0.6600000E-04	0.000000
A5_4	1400.000	0.000000
BETA5_4_6	0.2300000E-04	0.000000
T5_4_6	0.6020000E-01	0.000000
D5_4_6	0.9240000E-01	0.000000

U5_4_6	0.3220000E-01	0.000000
SU6_4_6	0.000000	0.000000
ST6_4_6	0.000000	0.000000
I6_4_6	0.000000	0.000000
ALFA6_4_6	0.6600000E-04	0.000000
A6_4	500.0000	0.000000
BETA6_4_6	0.2300000E-04	0.000000
T6_4_6	0.2150000E-01	0.000000
D6_4_6	0.3300000E-01	0.000000
U6_4_6	0.1150000E-01	0.000000
P4_6	0.000000	0.000000
L4_6	0.000000	0.000000
D4_6	0.1862000E-01	0.000000
I4_6	0.000000	0.000000
Q4_6	15.11732	0.000000
CSU1_4_6	12.50000	0.000000
CST1_4_6	9.500000	0.000000
CI1_4_6	10.00000	0.000000
CD1_4_6	1.500000	0.000000
CU1_4_6	1.118463	0.000000
CT1_4_6	1.118463	0.000000
R1_4_6	0.1011304E-04	0.000000
V1_4_6	996.0000	0.000000
CSU2_4_6	12.50000	0.000000
CST2_4_6	9.500000	0.000000
CI2_4_6	10.00000	0.000000
CD2_4_6	1.500000	0.000000
CU2_4_6	1.323556	0.000000
CT2_4_6	1.323556	0.000000
R2_4_6	0.1196748E-04	0.000000
V2_4_6	2530.000	0.000000
CSU3_4_6	12.50000	0.000000
CST3_4_6	9.500000	0.000000
CI3_4_6	10.00000	0.000000
CD3_4_6	1.500000	0.000000
CU3_4_6	1.206354	0.000000
CT3_4_6	1.206354	0.000000
R3_4_6	0.1090774E-04	0.000000
V3_4_6	31982.00	0.000000
CSU4_4_6	12.50000	0.000000
CST4_4_6	9.500000	0.000000
CI4_4_6	10.00000	0.000000
CD4_4_6	1.500000	0.000000
CU4_4_6	1.319990	0.000000
CT4_4_6	1.319990	0.000000
R4_4_6	0.1193523E-04	0.000000
V4_4_6	3484.000	0.000000
CSU5_4_6	12.50000	0.000000
CST5_4_6	9.500000	0.000000
CI5_4_6	10.00000	0.000000
CD5_4_6	1.500000	0.000000
CU5_4_6	1.278975	0.000000
CT5_4_6	1.278975	0.000000

R5_4_6	0.1156438E-04	0.000000
V5_4_6	1766.000	0.000000
CSU6_4_6	12.50000	0.000000
CST6_4_6	9.500000	0.000000
CI6_4_6	10.00000	0.000000
CD6_4_6	1.500000	0.000000
CU6_4_6	1.242887	0.000000
CT6_4_6	1.242887	0.000000
R6_4_6	0.1123807E-04	0.000000
V6_4_6	755.0000	0.000000
CP4_6	1.000000	0.000000
CL4_6	1.000000	0.000000
CD4_6	1.500000	0.000000
CI4_6	10.00000	0.000000
RQ4_6	0.3405665E-04	0.000000
C4_6	3.766533	0.000000
VQ4_6	268351.0	0.000000
SU1_5_6	0.000000	0.000000
ST1_5_6	0.000000	0.000000
I1_5_6	0.000000	0.000000
ALFA1_5_6	0.6600000E-04	0.000000
A1_5	8000.000	0.000000
BETA1_5_6	0.2300000E-04	0.000000
T1_5_6	0.3440000	0.000000
D1_5_6	0.5280000	0.000000
U1_5_6	0.1840000	0.000000
SU2_5_6	0.000000	0.000000
ST2_5_6	0.000000	0.000000
I2_5_6	0.000000	0.000000
ALFA2_5_6	0.6600000E-04	0.000000
A2_5	2400.000	0.000000
BETA2_5_6	0.2300000E-04	0.000000
T2_5_6	0.1032000	0.000000
D2_5_6	0.1584000	0.000000
U2_5_6	0.5520000E-01	0.000000
SU3_5_6	0.000000	0.000000
ST3_5_6	0.000000	0.000000
I3_5_6	0.000000	0.000000
ALFA3_5_6	0.6600000E-04	0.000000
A3_5	2100.000	0.000000
BETA3_5_6	0.2300000E-04	0.000000
T3_5_6	0.9030000E-01	0.000000
D3_5_6	0.1386000	0.000000
U3_5_6	0.4830000E-01	0.000000
SU4_5_6	0.000000	0.000000
ST4_5_6	0.000000	0.000000
I4_5_6	0.000000	0.000000
ALFA4_5_6	0.6600000E-04	0.000000
A4_5	750.0000	0.000000
BETA4_5_6	0.2300000E-04	0.000000
T4_5_6	0.3225000E-01	0.000000
D4_5_6	0.4950000E-01	0.000000
U4_5_6	0.1725000E-01	0.000000

SU5_5_6	0.000000	0.000000
ST5_5_6	0.000000	0.000000
I5_5_6	0.000000	0.000000
ALFA5_5_6	0.6600000E-04	0.000000
A5_5	900.0000	0.000000
BETA5_5_6	0.2300000E-04	0.000000
T5_5_6	0.3870000E-01	0.000000
D5_5_6	0.5940000E-01	0.000000
U5_5_6	0.2070000E-01	0.000000
P5_6	0.000000	0.000000
L5_6	0.000000	0.000000
I5_6	0.000000	0.000000
DSA5_6	0.2300000	0.000000
DAG5_6	0.9300000E-02	0.000000
Q5_6	15.96507	0.000000
CSU1_5_6	12.50000	0.000000
CST1_5_6	9.500000	0.000000
CI1_5_6	10.00000	0.000000
CD1_5_6	1.500000	0.000000
CU1_5_6	1.108330	0.000000
CT1_5_6	1.108330	0.000000
R1_5_6	0.1002142E-04	0.000000
V1_5_6	20636.00	0.000000
CSU2_5_6	12.50000	0.000000
CST2_5_6	9.500000	0.000000
CI2_5_6	10.00000	0.000000
CD2_5_6	1.500000	0.000000
CU2_5_6	1.267649	0.000000
CT2_5_6	1.267649	0.000000
R2_5_6	0.1146197E-04	0.000000
V2_5_6	3211.000	0.000000
CSU3_5_6	12.50000	0.000000
CST3_5_6	9.500000	0.000000
CI3_5_6	10.00000	0.000000
CD3_5_6	1.500000	0.000000
CU3_5_6	1.202583	0.000000
CT3_5_6	1.202583	0.000000
R3_5_6	0.1087365E-04	0.000000
V3_5_6	3791.000	0.000000
CSU4_5_6	12.50000	0.000000
CST4_5_6	9.500000	0.000000
CI4_5_6	10.00000	0.000000
CD4_5_6	1.500000	0.000000
CU4_5_6	1.264222	0.000000
CT4_5_6	1.264222	0.000000
R4_5_6	0.1143098E-04	0.000000
V4_5_6	1021.000	0.000000
CSU5_5_6	12.50000	0.000000
CST5_5_6	9.500000	0.000000
CI5_5_6	10.00000	0.000000
CD5_5_6	1.500000	0.000000
CU5_5_6	1.339346	0.000000
CT5_5_6	1.339346	0.000000

R5_5_6	0.1211024E-04	0.000000
V5_5_6	788.0000	0.000000
CP5_6	1.000000	0.000000
CL5_6	1.000000	0.000000
CI5_6	10.00000	0.000000
CDAG5_6	1.500000	0.000000
CDSA5_6	12.50000	0.000000
RQ5_6	0.2996042E-04	0.000000
C5_6	3.313506	0.000000
VQ5_6	255062.0	0.000000
SU1_6_6	0.000000	0.000000
ST1_6_6	0.000000	0.000000
I1_6_6	0.000000	0.000000
ALFA1_6_6	0.6600000E-04	0.000000
A1_6	4950.000	0.000000
BETA1_6_6	0.2300000E-04	0.000000
T1_6_6	0.2128500	0.000000
D1_6_6	0.3267000	0.000000
U1_6_6	0.1138500	0.000000
SU2_6_6	0.000000	0.000000
ST2_6_6	0.000000	0.000000
I2_6_6	0.000000	0.000000
ALFA2_6_6	0.6600000E-04	0.000000
A2_6	2700.000	0.000000
BETA2_6_6	0.2300000E-04	0.000000
T2_6_6	0.1161000	0.000000
D2_6_6	0.1782000	0.000000
U2_6_6	0.6210000E-01	0.000000
SU3_6_6	0.000000	0.000000
ST3_6_6	0.000000	0.000000
I3_6_6	0.000000	0.000000
ALFA3_6_6	0.6600000E-04	0.000000
A3_6	13700.00	0.000000
BETA3_6_6	0.2300000E-04	0.000000
T3_6_6	0.5891000	0.000000
D3_6_6	0.9042000	0.000000
U3_6_6	0.3151000	0.000000
SU4_6_6	0.000000	0.000000
ST4_6_6	0.000000	0.000000
I4_6_6	0.000000	0.000000
ALFA4_6_6	0.6600000E-04	0.000000
A4_6	61800.00	0.000000
BETA4_6_6	0.2300000E-04	0.000000
T4_6_6	2.657400	0.000000
D4_6_6	4.078800	0.000000
U4_6_6	1.421400	0.000000
P6_6	0.000000	0.000000
L6_6	0.000000	0.000000
I6_6	0.000000	0.000000
D6_6	0.7000000E-01	0.000000
Q6_6	19.61052	0.000000
CSU1_6_6	12.50000	0.000000
CST1_6_6	9.500000	0.000000

CI1_6_6	10.00000	0.000000
CD1_6_6	1.500000	0.000000
CU1_6_6	1.318493	0.000000
CT1_6_6	1.318493	0.000000
R1_6_6	0.1192169E-04	0.000000
V1_6_6	4974.000	0.000000
CSU2_6_6	12.50000	0.000000
CST2_6_6	9.500000	0.000000
CI2_6_6	10.00000	0.000000
CD2_6_6	1.500000	0.000000
CU2_6_6	1.287321	0.000000
CT2_6_6	1.287321	0.000000
R2_6_6	0.1163984E-04	0.000000
V2_6_6	3256.000	0.000000
CSU3_6_6	12.50000	0.000000
CST3_6_6	9.500000	0.000000
CI3_6_6	10.00000	0.000000
CD3_6_6	1.500000	0.000000
CU3_6_6	1.056594	0.000000
CT3_6_6	1.056594	0.000000
R3_6_6	0.9553628E-05	0.000000
V3_6_6	41966.00	0.000000
CSU4_6_6	12.50000	0.000000
CST4_6_6	9.500000	0.000000
CI4_6_6	10.00000	0.000000
CD4_6_6	1.500000	0.000000
CU4_6_6	1.002616	0.000000
CT4_6_6	1.002616	0.000000
R4_6_6	0.9065566E-05	0.000000
V4_6_6	223784.0	0.000000
CP6_6	1.000000	0.000000
CL6_6	1.000000	0.000000
CI6_6	10.00000	0.000000
CD6_6	1.500000	0.000000
RQ6_6	0.2224278E-04	0.000000
C6_6	2.459965	0.000000
VQ6_6	381294.0	0.000000
SU1_7_6	0.000000	0.000000
ST1_7_6	0.000000	0.000000
I1_7_6	0.000000	0.000000
ALFA1_7_6	0.6600000E-04	0.000000
A1_7	8700.000	0.000000
BETA1_7_6	0.1100000E-04	0.000000
T1_7_6	0.4785000	0.000000
D1_7_6	0.5742000	0.000000
U1_7_6	0.9570000E-01	0.000000
SU2_7_6	0.000000	0.000000
ST2_7_6	0.000000	0.000000
I2_7_6	0.000000	0.000000
ALFA2_7_6	0.6600000E-04	0.000000
A2_7	1000.000	0.000000
BETA2_7_6	0.1100000E-04	0.000000
T2_7_6	0.5500000E-01	0.000000

D2_7_6	0.6600000E-01	0.000000
U2_7_6	0.1100000E-01	0.000000
SU3_7_6	0.000000	0.000000
ST3_7_6	1.440000	0.000000
I3_7_6	0.000000	0.000000
ALFA3_7_6	0.6600000E-04	0.000000
A3_7	5300.000	0.000000
BETA3_7_6	0.1100000E-04	0.000000
T3_7_6	1.731500	0.000000
D3_7_6	0.3498000	0.000000
U3_7_6	0.5830000E-01	0.000000
P7_6	0.000000	0.000000
L7_6	0.000000	0.000000
I7_6	0.000000	0.000000
D7_6	0.000000	0.000000
Q7_6	21.87552	0.000000
CSU1_7_6	12.50000	0.000000
CST1_7_6	9.500000	0.000000
CI1_7_6	10.00000	0.000000
CD1_7_6	1.500000	0.000000
CU1_7_6	1.278502	0.000000
CT1_7_6	1.278502	0.000000
R1_7_6	0.1156010E-04	0.000000
V1_7_6	11002.00	0.000000
CSU2_7_6	12.50000	0.000000
CST2_7_6	9.500000	0.000000
CI2_7_6	10.00000	0.000000
CD2_7_6	1.500000	0.000000
CU2_7_6	1.429685	0.000000
CT2_7_6	1.429685	0.000000
R2_7_6	0.1292708E-04	0.000000
V2_7_6	359.0000	0.000000
TAU3_7_6	0.4200000	0.000000
CIN3_7_6	9.500000	0.000000
CT3_7_6	9.499964	0.000000
CP7_6	1.000000	0.000000
CL7_6	1.000000	0.000000
CI7_6	10.00000	0.000000
CD7_6	1.500000	0.000000
RQ7_6	0.2392487E-04	0.000000
C7_6	2.645998	0.000000
VQ7_6	313406.0	0.000000
Q8_6	5.050000	0.000000
C8_6	1.200000	0.000000
SU1_9_6	0.000000	0.000000
ST1_9_6	23.15000	0.000000
I1_9_6	0.000000	0.000000
ALFA1_9_6	0.6600000E-04	0.000000
A1_9	7000.000	0.000000
BETA1_9_6	0.1100000E-04	0.000000
T1_9_6	23.53500	0.000000
D1_9_6	0.4620000	0.000000
U1_9_6	0.7700000E-01	0.000000

SU2_9_6	0.000000	0.000000
ST2_9_6	0.1100000	0.000000
I2_9_6	0.000000	0.000000
ALFA2_9_6	0.6600000E-04	0.000000
A2_9	1900.000	0.000000
BETA2_9_6	0.1100000E-04	0.000000
T2_9_6	0.2145000	0.000000
D2_9_6	0.1254000	0.000000
U2_9_6	0.2090000E-01	0.000000
P9_6	0.000000	0.000000
L9_6	0.000000	0.000000
I9_6	0.000000	0.000000
DAG9_6	0.000000	0.000000
DSA9_6	0.1380000	0.000000
Q9_6	28.93750	0.000000
TAU1_9_6	0.1800000	0.000000
CIN1_9_6	9.500000	0.000000
CT1_9_6	9.499985	0.000000
CSU2_9_6	12.50000	0.000000
CST2_9_6	9.500000	0.000000
CI2_9_6	10.00000	0.000000
CD2_9_6	1.500000	0.000000
CU2_9_6	4.492805	0.000000
CT2_9_6	4.492805	0.000000
R2_9_6	0.4062354E-04	0.000000
V2_9_6	4320.000	0.000000
CP9_6	1.000000	0.000000
CL9_6	1.000000	0.000000
CI9_6	10.00000	0.000000
CDAG9_6	1.500000	0.000000
CDSA9_6	9.500000	0.000000
RB9_6	0.5690564E-04	0.000000
C9_6	6.293543	0.000000
VB9_6	875088.0	0.000000
SU1_10_6	0.000000	0.000000
ST1_10_6	0.000000	0.000000
I1_10_6	0.000000	0.000000
ALFA1_10_6	0.6600000E-04	0.000000
A1_10	9600.000	0.000000
BETA1_10_6	0.1100000E-04	0.000000
T1_10_6	0.5280000	0.000000
D1_10_6	0.6336000	0.000000
U1_10_6	0.1056000	0.000000
SU2_10_6	0.000000	0.000000
ST2_10_6	0.000000	0.000000
I2_10_6	0.000000	0.000000
ALFA2_10_6	0.6600000E-04	0.000000
A2_10	16000.00	0.000000
BETA2_10_6	0.6600000E-04	0.000000
T2_10_6	0.000000	0.000000
D2_10_6	1.056000	0.000000
U2_10_6	1.056000	0.000000
P10_6	0.000000	0.000000

L10_6	0.000000	0.000000
I10_6	0.000000	0.000000
DAG10_6	0.000000	0.000000
DSA10_6	0.4630000	0.000000
Q10_6	29.92850	0.000000
CSU1_10_6	12.50000	0.000000
CST1_10_6	9.500000	0.000000
CI1_10_6	10.00000	0.000000
CD1_10_6	1.500000	0.000000
CU1_10_6	1.254591	0.000000
CT1_10_6	1.254591	0.000000
R1_10_6	0.1134390E-04	0.000000
V1_10_6	13707.00	0.000000
CSU2_10_6	12.50000	0.000000
CST2_10_6	9.500000	0.000000
CI2_10_6	10.00000	0.000000
CD2_10_6	1.500000	0.000000
CU2_10_6	1.323679	0.000000
CT2_10_6	1.323679	0.000000
R2_10_6	0.1196858E-04	0.000000
V2_10_6	15557.00	0.000000
CP10_6	1.000000	0.000000
CL10_6	1.000000	0.000000
CI10_6	10.00000	0.000000
RB10_6	0.4027032E-04	0.000000
C10_6	4.453741	0.000000
VB10_6	1338120.	0.000000
CDAG10_6	1.500000	0.000000
CDSA10_6	9.500000	0.000000
SU1_11_6	0.000000	0.000000
ST1_11_6	0.000000	0.000000
I1_11_6	0.000000	0.000000
ALFA1_11_6	0.6600000E-04	0.000000
A1_11	1500.000	0.000000
BETA1_11_6	0.1100000E-04	0.000000
T1_11_6	0.8250000E-01	0.000000
D1_11_6	0.9900000E-01	0.000000
U1_11_6	0.1650000E-01	0.000000
SU2_11_6	0.000000	0.000000
ST2_11_6	0.000000	0.000000
I2_11_6	0.000000	0.000000
ALFA2_11_6	0.6600000E-04	0.000000
A2_11	3000.000	0.000000
BETA2_11_6	0.1100000E-04	0.000000
T2_11_6	0.1650000	0.000000
D2_11_6	0.1980000	0.000000
U2_11_6	0.3300000E-01	0.000000
SU3_11_6	0.000000	0.000000
ST3_11_6	0.000000	0.000000
I3_11_6	0.000000	0.000000
ALFA3_11_6	0.6600000E-04	0.000000
A3_11	31000.00	0.000000
BETA3_11_6	0.1100000E-04	0.000000

T3_11_6	1.705000	0.000000
D3_11_6	2.046000	0.000000
U3_11_6	0.3410000	0.000000
QT_6	51.80402	0.000000
P11_6	0.000000	0.000000
L11_6	0.000000	0.000000
I11_6	0.000000	0.000000
D11_6	0.3900000	0.000000
Q11_6	54.14652	0.000000
CSU1_11_6	12.50000	0.000000
CST1_11_6	9.500000	0.000000
CI1_11_6	10.00000	0.000000
CD1_11_6	1.500000	0.000000
CU1_11_6	1.285798	0.000000
CT1_11_6	1.285798	0.000000
R1_11_6	0.1162607E-04	0.000000
V1_11_6	1824.000	0.000000
CSU2_11_6	12.50000	0.000000
CST2_11_6	9.500000	0.000000
CI2_11_6	10.00000	0.000000
CD2_11_6	1.500000	0.000000
CU2_11_6	1.236151	0.000000
CT2_11_6	1.236151	0.000000
R2_11_6	0.1117717E-04	0.000000
V2_11_6	4674.000	0.000000
CSU3_11_6	12.50000	0.000000
CST3_11_6	9.500000	0.000000
CI3_11_6	10.00000	0.000000
CD3_11_6	1.500000	0.000000
CU3_11_6	1.182228	0.000000
CT3_11_6	1.182228	0.000000
R3_11_6	0.1068959E-04	0.000000
V3_11_6	60822.00	0.000000
CT_6	3.690377	0.000000
CP11_6	1.000000	0.000000
CL11_6	1.000000	0.000000
CD11_6	1.500000	0.000000
CI11_6	10.00000	0.000000
RR11_6	0.2815429E-04	0.000000
C11_6	3.113755	0.000000
VR11_6	905301.0	0.000000
SU1_12_6	0.000000	0.000000
ST1_12_6	0.2310000	0.000000
I1_12_6	0.000000	0.000000
ALFA1_12_6	0.6600000E-04	0.000000
A1_12	11500.00	0.000000
BETA1_12_6	0.2300000E-04	0.000000
T1_12_6	0.7255000	0.000000
D1_12_6	0.7590000	0.000000
U1_12_6	0.2645000	0.000000
SU2_12_6	0.000000	0.000000
ST2_12_6	0.000000	0.000000
I2_12_6	0.000000	0.000000

ALFA2_12_6	0.6600000E-04	0.000000
A2_12	2000.000	0.000000
BETA2_12_6	0.2300000E-04	0.000000
T2_12_6	0.8600000E-01	0.000000
D2_12_6	0.1320000	0.000000
U2_12_6	0.4600000E-01	0.000000
SU3_12_6	0.000000	0.000000
ST3_12_6	0.000000	0.000000
I3_12_6	0.000000	0.000000
ALFA3_12_6	0.6600000E-04	0.000000
A3_12	6000.000	0.000000
BETA3_12_6	0.2300000E-04	0.000000
T3_12_6	0.2580000	0.000000
D3_12_6	0.3960000	0.000000
U3_12_6	0.1380000	0.000000
P12_6	0.000000	0.000000
L12_6	0.000000	0.000000
I12_6	0.000000	0.000000
DAG12_6	0.5970000	0.000000
DSA12_6	0.2310000	0.000000
Q12_6	56.04402	0.000000
CSU1_12_6	12.50000	0.000000
CST1_12_6	9.500000	0.000000
CI1_12_6	10.00000	0.000000
CD1_12_6	1.500000	0.000000
CU1_12_6	2.857890	0.000000
CT1_12_6	2.857890	0.000000
R1_12_6	0.2584078E-04	0.000000
V1_12_6	19492.00	0.000000
CSU2_12_6	12.50000	0.000000
CST2_12_6	9.500000	0.000000
CI2_12_6	10.00000	0.000000
CD2_12_6	1.500000	0.000000
CU2_12_6	1.284366	0.000000
CT2_12_6	1.284366	0.000000
R2_12_6	0.1161312E-04	0.000000
V2_12_6	2451.000	0.000000
CSU3_12_6	12.50000	0.000000
CST3_12_6	9.500000	0.000000
CI3_12_6	10.00000	0.000000
CD3_12_6	1.500000	0.000000
CU3_12_6	1.309480	0.000000
CT3_12_6	1.309480	0.000000
R3_12_6	0.1184020E-04	0.000000
V3_12_6	6372.000	0.000000
CP12_6	1.000000	0.000000
CL12_6	1.000000	0.000000
CI12_6	10.00000	0.000000
CDAG12_6	1.500000	0.000000
CDSA12_6	9.500000	0.000000
RR12_6	0.2374678E-04	0.000000
C12_6	2.626302	0.000000
VR12_6	1137931.	0.000000

SU1_13_6	0.000000	0.000000
ST1_13_6	0.000000	0.000000
I1_13_6	0.000000	0.000000
ALFA1_13_6	0.6600000E-04	0.000000
A1_13	17000.00	0.000000
BETA1_13_6	0.2300000E-04	0.000000
T1_13_6	0.7310000	0.000000
D1_13_6	1.122000	0.000000
U1_13_6	0.3910000	0.000000
SU2_13_6	0.000000	0.000000
ST2_13_6	0.000000	0.000000
I2_13_6	0.000000	0.000000
ALFA2_13_6	0.6600000E-04	0.000000
A2_13	10100.00	0.000000
BETA2_13_6	0.2300000E-04	0.000000
T2_13_6	0.4343000	0.000000
D2_13_6	0.6666000	0.000000
U2_13_6	0.2323000	0.000000
P13_6	0.000000	0.000000
L13_6	0.000000	0.000000
D13_6	0.4650000	0.000000
I13_6	0.000000	0.000000
Q13_6	57.67432	0.000000
CT1_13_6	0.2200000	0.000000
CSU2_13_6	12.50000	0.000000
CST2_13_6	9.500000	0.000000
CI2_13_6	10.00000	0.000000
CD2_13_6	1.500000	0.000000
CU2_13_6	1.250504	0.000000
CT2_13_6	1.250504	0.000000
R2_13_6	0.1130695E-04	0.000000
V2_13_6	14709.00	0.000000
CP13_6	1.000000	0.000000
CL13_6	1.000000	0.000000
CD13_6	1.500000	0.000000
CI13_6	10.00000	0.000000
RR13_6	0.1818396E-04	0.000000
C13_6	2.011075	0.000000
VR13_6	1792928.	0.000000
SU1_14_6	0.000000	0.000000
ST1_14_6	0.000000	0.000000
I1_14_6	0.000000	0.000000
ALFA1_14_6	0.6600000E-04	0.000000
A1_14	17000.00	0.000000
BETA1_14_6	0.2300000E-04	0.000000
T1_14_6	0.7310000	0.000000
D1_14_6	1.122000	0.000000
U1_14_6	0.3910000	0.000000
SU2_14_6	0.000000	0.000000
ST2_14_6	0.000000	0.000000
I2_14_6	0.000000	0.000000
ALFA2_14_6	0.6600000E-04	0.000000
A2_14	47000.00	0.000000

BETA2_14_6	0.2300000E-04	0.000000
T2_14_6	2.021000	0.000000
D2_14_6	3.102000	0.000000
U2_14_6	1.081000	0.000000
P14_6	0.000000	0.000000
L14_6	0.000000	0.000000
I14_6	0.000000	0.000000
DAG14_6	0.5576000E-01	0.000000
DSA14_6	0.2300000	0.000000
R14_6	2.060000	0.000000
Q14_6	58.65208	0.000000
CT1_14_6	0.9500000	0.000000
CT2_14_6	0.5000000	0.000000
CP14_6	1.000000	0.000000
CL14_6	1.000000	0.000000
CI14_6	10.00000	0.000000
CDAG14_6	1.500000	0.000000
CDSA14_6	9.500000	0.000000
C14_6	1.436589	0.000000
CR14_6	1.436589	0.000000
RR14_6	0.1298950E-04	0.000000
VR14_6	2520704.	0.000000
SU1_15_6	0.000000	0.000000
ST1_15_6	0.000000	0.000000
I1_15_6	0.000000	0.000000
ALFA1_15_6	0.6600000E-04	0.000000
A1_15	47320.00	0.000000
BETA1_15_6	0.2300000E-04	0.000000
T1_15_6	2.034760	0.000000
D1_15_6	3.123120	0.000000
U1_15_6	1.088360	0.000000
SU2_15_6	0.000000	0.000000
ST2_15_6	0.000000	0.000000
I2_15_6	0.000000	0.000000
ALFA2_15_6	0.6600000E-04	0.000000
A2_15	57500.00	0.000000
BETA2_15_6	0.2300000E-04	0.000000
T2_15_6	2.472500	0.000000
D2_15_6	3.795000	0.000000
U2_15_6	1.322500	0.000000
P15_6	0.000000	0.000000
L15_6	0.000000	0.000000
I15_6	0.000000	0.000000
D15_6	0.000000	0.000000
Q15_6	63.15934	0.000000
CT1_15_6	0.9500000	0.000000
CT2_15_6	0.9500000	0.000000
CP15_6	1.000000	0.000000
CL15_6	1.000000	0.000000
CI15_6	10.00000	0.000000
CD15_6	1.500000	0.000000
RR15_6	0.1175448E-04	0.000000
VR15_6	547338.0	0.000000

APPENDIX C

LINGO OPTIMIZATION FORMULATION FOR THE EIP CASE STUDY

```
! The symbols used are W forflowrate of a source, ys for supply composition of a
source, waste is flowrate of source going to waste, Cint is cost of interception;
! Fint is flowrate going to the interceptor, Yin is compotion entering interceptor and
yout composition leaving interceptor, YminIn and YminOut are minimum inlet and
outlet compositions for the interceptor;
! G is flowrate entering the sink, zmax max allowable composition to sink, Z is actual
composition entering the sink, and F is fresh used in sink;
! D is direct recycle flowrate from source to sink, U is flowrate between source and
interceptor and V is flowrate between interceptor and sink;
! indices are i for source, k for interceptor, and j for sink;
SETS:
SOURCES /1..5/: W, Ys, Waste;
INTERCEPTORS /1..5/: Cint, Fint, Yin, Yout, YminIn, YminOut;
SINKS /1..4/: G, ZMAX, Z, F;
DIRECT_RECYCLE(SOURCES, SINKS): D;
FLOW_CONNECTIONS (SOURCES, INTERCEPTORS): U;
FLOW_SPLITS (INTERCEPTORS, SINKS): V;
ENDSETS
DATA:
W = 3000   1000   3000   1300   200;
Ys = 50      400    1100    1600   1800;
G =       2500   2000   3500    1000;
ZMAX = 40       225      500      760;
! the cost given in the data are $ per kg but here we multiple times ton/hr times ppm
which gives gm per hr, therefore we need to divide the cost by 1000;
Cint = 0.00005    0.00006     0.00008     0.00009    0.00016 ;
YminIn = 1000   800    370    300   280;
YminOut = 450   300   250   100   30 ;
ENDDATA

min= (Fresh_Cost + Interception_Cost);
Fresh_Cost = Cfresh*Fresh*8760;
Interception_Cost = (@SUM(INTERCEPTORS(k): Cint(k)*Fint(k)*((Yin(k)-
Yout(k)))))*8760;
@FOR (INTERCEPTORS(k): Yin(k) >=Yout(k));
```

```
Fresh = @SUM( SINKS( j): F(j));
XF = 0;
Cfresh = 0.6;
Fresh >=0;
!Splitting of source i to all interceptors, sinks, and waste;
@FOR (SOURCES(i):
 @SUM( INTERCEPTORS(k): U(i,k)) + @SUM( SINKS(j): D(i,j)) + Waste(i) =
W(i));

!Mixing of flow from interceptor k to all sinks;
@FOR (INTERCEPTORS(k):
        @SUM( SOURCES(i): U(i,k)) = Fint(k));
@FOR (INTERCEPTORS(k):
        @SUM( SOURCES(i): U(i,k)*Ys(i)) = Fint(k)*Yin(k));

@FOR (INTERCEPTORS(k):
        Yin(k) >= Yout(k));

@FOR (INTERCEPTORS(k):
        Yin(k) >= YminIn(k));

@FOR (INTERCEPTORS(k):
        Yout(k) >= YminOut(k));

@FOR (INTERCEPTORS(k):
        @SUM( SINKS(j): V(k,j)) = Fint(k));
@FOR (SINKS(j):
        @SUM( INTERCEPTORS(k): V(k,j)) + @SUM( SOURCES(i): D(i,j))  = G(j) -
F(j));
@FOR (SINKS(j):
        @SUM( INTERCEPTORS(k): V(k,j)*Yout(k)) + @SUM( SOURCES(i):
D(i,j)*Ys(i))  = G(j)*Z(j) - F(j)*Xf);
@FOR (SINKS(j):  Z(j) <= ZMAX(j));
```

```
 Global optimal solution found.
 Objective value:                    4042740.
 Extended solver steps:                    1
 Total solver iterations:                558

                       Variable           Value        Reduced Cost
                     FRESH_COST        2628000.            0.000000
             INTERCEPTION_COST        1414740.            0.000000
```

CFRESH	0.6000000	0.000000
FRESH	500.0000	0.000000
XF	0.000000	0.000000
W(1)	3000.000	0.000000
W(2)	1000.000	0.000000
W(3)	3000.000	0.000000
W(4)	1300.000	0.000000
W(5)	200.0000	0.000000
YS(1)	50.00000	0.000000
YS(2)	400.0000	0.000000
YS(3)	1100.000	0.000000
YS(4)	1600.000	0.000000
YS(5)	1800.000	0.000000
WASTE(1)	0.000000	5234.100
WASTE(2)	0.000000	5080.800
WASTE(3)	0.000000	4774.200
WASTE(4)	0.000000	4555.200
WASTE(5)	0.000000	4467.600
CINT(1)	0.5000000E-04	0.000000
CINT(2)	0.6000000E-04	0.000000
CINT(3)	0.8000000E-04	0.000000
CINT(4)	0.9000000E-04	0.000000
CINT(5)	0.1600000E-03	0.000000
FINT(1)	4300.000	0.000000
FINT(2)	0.000000	0.000000
FINT(3)	0.000000	0.000000
FINT(4)	0.000000	0.000000
FINT(5)	0.000000	0.000000
YIN(1)	1251.163	0.000000
YIN(2)	800.0000	0.000000
YIN(3)	653.0556	0.000000
YIN(4)	2894.198	0.000000
YIN(5)	394.2653	0.000000
YOUT(1)	500.0000	0.000000
YOUT(2)	800.0000	0.000000
YOUT(3)	653.0556	0.000000
YOUT(4)	2894.198	0.000000
YOUT(5)	394.2653	0.000000
YMININ(1)	1000.000	0.000000
YMININ(2)	800.0000	0.000000
YMININ(3)	370.0000	0.000000
YMININ(4)	300.0000	0.000000
YMININ(5)	280.0000	0.000000

YMINOUT(1)	450.0000	0.000000
YMINOUT(2)	300.0000	0.000000
YMINOUT(3)	250.0000	0.000000
YMINOUT(4)	100.0000	0.000000
YMINOUT(5)	30.00000	0.000000
G(1)	2500.000	0.000000
G(2)	2000.000	0.000000
G(3)	3500.000	0.000000
G(4)	1000.000	0.000000
ZMAX(1)	40.00000	0.000000
ZMAX(2)	225.0000	0.000000
ZMAX(3)	500.0000	0.000000
ZMAX(4)	760.0000	0.000000
Z(1)	40.00000	0.000000
Z(2)	225.0000	0.000000
Z(3)	500.0000	0.000000
Z(4)	760.0000	0.000000
F(1)	500.0000	0.000000
F(2)	0.000000	0.000000
F(3)	0.000000	0.000000
F(4)	0.000000	0.000000
D(1, 1)	2000.000	0.000000
D(1, 2)	1000.000	0.000000
D(1, 3)	0.000000	0.000000
D(1, 4)	0.000000	0.000000
D(2, 1)	0.000000	0.000000
D(2, 2)	1000.000	0.000000
D(2, 3)	0.000000	0.000000
D(2, 4)	0.000000	0.000000
D(3, 1)	0.000000	0.000000
D(3, 2)	0.000000	0.000000
D(3, 3)	0.000000	0.000000
D(3, 4)	0.000000	0.000000
D(4, 1)	0.000000	0.000000
D(4, 2)	0.000000	0.000000
D(4, 3)	0.000000	0.000000
D(4, 4)	0.000000	0.000000
D(5, 1)	0.000000	0.000000
D(5, 2)	0.000000	0.000000
D(5, 3)	0.000000	0.000000
D(5, 4)	200.0000	0.000000
U(1, 1)	0.000000	0.000000
U(1, 2)	0.000000	0.000000

U(1, 3)	0.000000	0.000000
U(1, 4)	0.000000	0.000000
U(1, 5)	0.000000	0.000000
U(2, 1)	0.000000	0.000000
U(2, 2)	0.000000	0.000000
U(2, 3)	0.000000	0.000000
U(2, 4)	0.000000	0.000000
U(2, 5)	0.000000	0.000000
U(3, 1)	3000.000	0.000000
U(3, 2)	0.000000	0.000000
U(3, 3)	0.000000	0.000000
U(3, 4)	0.000000	0.000000
U(3, 5)	0.000000	0.000000
U(4, 1)	1300.000	0.000000
U(4, 2)	0.000000	0.000000
U(4, 3)	0.000000	0.000000
U(4, 4)	0.000000	0.000000
U(4, 5)	0.000000	0.000000
U(5, 1)	0.000000	0.000000
U(5, 2)	0.000000	0.000000
U(5, 3)	0.000000	0.000000
U(5, 4)	0.000000	0.000000
U(5, 5)	0.000000	0.000000
V(1, 1)	0.000000	0.000000
V(1, 2)	0.000000	0.000000
V(1, 3)	3500.000	0.000000
V(1, 4)	800.0000	0.000000
V(2, 1)	0.000000	0.000000
V(2, 2)	0.000000	0.000000
V(2, 3)	0.000000	0.000000
V(2, 4)	0.000000	0.000000
V(3, 1)	0.000000	0.000000
V(3, 2)	0.000000	0.000000
V(3, 3)	0.000000	0.000000
V(3, 4)	0.000000	0.000000
V(4, 1)	0.000000	0.000000
V(4, 2)	0.000000	0.000000
V(4, 3)	0.000000	0.000000
V(4, 4)	0.000000	0.000000
V(5, 1)	0.000000	0.000000
V(5, 2)	0.000000	0.000000
V(5, 3)	0.000000	0.000000
V(5, 4)	0.000000	0.000000

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