Wastewater Management along the Mediterranean Coast: A Treatment Application Decision Case Study

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ABSTRACT

The Council for Development and Reconstruction, which needed to make decisions regarding the development of a wastewater management plan for the City of Beirut, was in the process of selecting a final site location and a treatment alternative for a facility along the Mediterranean coast. Environmental, technical, and socio-economic considerations constituted the basic issues to be addressed in the decision-making process. In this respect, proponents of the new wastewater treatment plant stated that it would provide many environmental and economic benefits to the area, particularly in terms of job creation and elimination of health hazards. Opponents of the plant, however, stressed that there was no need for the plant and argued that the wastewater should continue to be directly discharged into the Mediterranean Sea. They claimed that the dilution and treatment potential of seawater is adequate as a wastewater management approach and questioned the economic priority of constructing new treatment facilities in the country because of more urgent needs in other sectors, particularly since treatment facilities were being financed through international loans. Despite some public opposition, environmental concerns and international pressure led the Council to adopt a management plan that required wastewater treatment prior to final discharge. The council however, needed to decide on criteria for locating treatment facilities, determine the level of treatment, and select the final discharge media.

UNTREATED WASTEWATER usually contains numerous pathogenic microorganisms and toxic compounds that can cause various diseases, as well as nutrients that can stimulate the growth of aquatic plants. Historically, wastewater collected from communities was ultimately discharged to receiving waters (water bodies such as rivers, lakes, and oceans) or land. Continuous population growth, particularly in urban areas, led to serious deterioration of water resources and consequently, effluent discharge standards were developed and are being adopted on a global scale. Therefore, proper wastewater management is now being increasingly required to ensure a sustainable environment through protecting public health, maintaining aquatic ecosystems, and improving and protecting drinking water resources. The questions of how wastewater should be managed and to what extent it should be treated before discharge must be answered, taking into consideration local conditions and applicable regulation, while applying scientific knowledge and judgement based on past experience.

In Lebanon, as in many developing countries, nuisance, health conditions, and public pressure brought about an increasing demand for more effective means of wastewater management, particularly in large metropolitan areas along the Mediterranean Sea. This paper considers the decision of the Lebanese Council for Development and Reconstruction (CDR) on criteria for locating a treatment facility for the city of Beirut, determining the level of treatment, and selecting the final discharge media. This council coordinates major infrastructure and developmental projects with various ministries and municipalities across the country. It reports directly to the Council of Ministers, the highest executive branch in the country.

The case was developed for use in senior undergraduate and graduate level courses in environmental engineering and science. Besides the stress on the technical component of wastewater treatment alternatives, the case can serve to discuss wastewater management in light of social perceptions in general, and limited economic resources in particular. Finally, an important aspect of the case study approach is to encourage students to seek additional information, data, or references that are needed to reach an informed scientific decision, thus allowing the simulation of real-time decision-making, which has to often be made in the absence of data due to economic or technical constraints.

THE CASE

Lebanon is located along the eastern shore of the Mediterranean sea (Exhibit 1) extending about 225 km long and possessing jurisdiction over about 20 km territorial limit of oceanic waters. Being a signatory of several international conventions for the protection of the Mediterranean from environmental pollution, Lebanon has the responsibility, in part, for the manner in which it uses this zone. Years of civil unrest accompanied with major demographic changes, unplanned development, and inadequate institutional support have hindered Lebanon from developing environmental management and control procedures to comply with its commitments. As such, domestic wastewater in Lebanon was discharged into the Mediterranean Sea with no treatment prior to disposal. Environmental impacts associated with open sea disposal of untreated wastewater had raised international as well as local concerns in recent years particularly with the continuously increasing population of major cities along the coastline. Environmental concerns and population increase coupled with pressure to comply with international treaties, as well as the anticipation of economic growth, had placed severe pressure on the government to undertake immediate remedial action and long-term planning, particularly regarding the need for renovating existing wastewater collection and disposal systems, and constructing new treatment facilities.

Abbreviations: CDR, Council for Development and Reconstruction; BOD, biochemical oxygen demand; COD, chemical oxygen demand; SS, suspended solids; TDS, total dissolved solids; DDT, dichloro diphenyl trichloroethane; PCB, polychlorinated biphenyls.

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Although CDR was initially conceived in the early 1970s as a policy planning entity, its role has progressed with time to develop, supervise, and implement policies and major projects. It consists of several departments responsible for various economic sectors including transportation, energy, industry, agriculture, and waste management. Its highest authority consists of a board of four members that are the ultimate decision makers who make decisions by majority. Their decisions can be overruled only by the president of the CDR and/or the Council of Ministers. Each board member is directly supported by technical and administrative personnel or can draw on the expertise of the various departments of the council.

**Existing Wastewater Systems**

Damage assessment reports following years of civil unrest revealed that many wastewater collection systems had deteriorated to a degree that remedial action was needed to render them serviceable (Dar Al-Handasah and International Bechtel, 1991). In fact, not a single wastewater treatment plant in the country was operational. Damage assessment reports provided evidence suggesting that disposal systems, whether on-lot or community-based, presented an environmental hazard to the local townspeople either through direct exposure or indirectly through contamination of water resources, coastal recreation areas, and agricultural lands. As postwar rehabilitation and resettlement proceeded, new sewerage systems or extensions of existing systems, were being planned and installed. In many cases, accessible treatment facilities did not exist and provisions were not included for package plants or other temporary facilities. Environmental contamination unavoidably occurred around and downstream of discharge points.

**Adverse Health and Environmental Impacts**

Data on the quality of Lebanese coastal waters were relatively limited, but marine pollution of the Mediterranean was well-documented (World Bank, 1989). Discharge of untreated sewage into coastal waters had been the common practice (Exhibits 2 and 3). Other sources of marine pollution included solid and industrial waste disposal, chronic release of petroleum wastes or products including oil tanker accidents, as well as excessive levels of nutrients that were generated from agricultural areas where nitrates and phosphorus were washed away from agricultural land and were carried by wastewater collection systems into the sea.

Although the effect of this direct discharge had not been adequately characterized, several local studies reported the presence of metals (mercury 10–250 µg/kg, copper 120–900 µg/kg, cadmium 2–25 µg/kg) and pesticides (DDT 3–150 µg/kg and PCB 0–90 µg/kg) in several types of fish (Keyomjian and Safa, 1993). Chemical analysis of sea water samples revealed the presence of concentrations of several nutrients (phosphates, nitrates, and nitrites) and elevated total coliform (30–11 000 colonies per 100 mL, depending on the sampling location). The solution to potentially adverse effects associated with the presence of these chemicals in fish and seawater samples lay in the construction of sewage treatment plants for cities with population >100 000 (World Bank, 1989). In some cases, this solution was technologically and economically burdensome, particularly in countries with limited financial resources.

**Marine Protection Requirements**

The government of Lebanon, being a signatory to the Convention for the Protection of the Mediterranean Sea against
Pollution and its three associated protocols (1975–1989), was committed to adopting these protocols and associated guidelines and standards that relate to marine water quality. The objective of these protocols was the protection of bathing beaches, which required that toxic and nonbiodegradable substances be excluded from wastewater discharges and that a suitable combination of treatment and offshore dilution be provided.

Existing Water Wells

During the period of civil unrest, the extensive need for water along with the inability of the government to act effectively encouraged the residents to drill private water wells. Such privately owned and operated wells were scattered throughout the country. In Beirut alone, because of lack of control and inadequate public water supply, some 10,000 privately owned wells supplemented the water systems managed by the official water authorities. The excessively high extraction rate of ground water from these densely situated wells had approached a crisis state, and had actually surpassed the natural recharge rate and a significant proportion of these cases resulted in serious salt water intrusion problems (Akkr, 1992; Aera, 1992). Many wells had also been a source of public health hazards because of inadequate maintenance and operation.

National Water Balance

Planning for future consumption of fresh water was of vital importance because the available supply was finite and needed to be apportioned to various uses in proportion to their economic and social importance. A water balance was used to project current and future water demands and to devise plans to reach the estimated future water demands. Estimates of the current and future water balance for Lebanon are presented in Exhibits 4 and 5. These forecast a serious deficit in the water balance in the future, as further emphasized in Exhibit 6.

Considering that water resources in Lebanon are limited, it is imperative that all available water resources be considered as a source for domestic water supply or agricultural use. In the case of aquifer recharge, it is of utmost importance that effluent criteria comprise prescribed minimization of pathogenic and organic contamination with compliance to potable drinking water standards for nondegradable constituents.

The Need for Wastewater Treatment

Despite the adverse environmental impacts associated with wastewater disposal into the sea, several interest groups opposed the construction of a new wastewater treatment plant for various reasons, including site location, economic, and political issues. Their argument was that the government was seeking to finance the construction of treatment facilities through international loans and under international pressure. The CDR that was responsible for making the final decision regarding the development of a wastewater management plan for the city of Beirut was under public scrutiny. The problem was whether or not to construct a new wastewater treatment...
facility, and if so, to select a site location and treatment alternative.

WASTEWATER TREATMENT ALTERNATIVES

Planners faced the problem of developing appropriate wastewater treatment alternatives, which in the case of Beirut are highly dependent on the site location. Land availability along the Beirut coast was limited and, when available, the cost was prohibitively expensive, which in turn would affect the treatment process and the extent of wastewater treatment before final discharge. Wastewater quantity and characteristics, as well as effluent discharge standards, were essential parameters for the selection and design of a treatment process.

Wastewater Quantity

Prior to the design of wastewater treatment facilities, it was necessary to determine the quantities of wastewater generated that will be treated at the proposed facility. Then, wastewater facilities could be designed to treat and discharge projected future flows, which were directly proportional to water consumption. In this respect, the national water balance was useful to some extent; however, additional data on population estimates and average water consumption per capita were typically needed. These data for Beirut are presented in Exhibit 7. Methods of wastewater treatment to be adopted varied with the wastewater characteristics and the end use of the product water, and consequently with the level of treatment required.

Wastewater Characteristics

Wastewater is typically characterized in terms of several parameters such as: biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), and total dissolved solids (TDS). Determining the concentrations of other parameters such as nutrients (phosphorus, nitrate) and toxic metals also prove helpful in evaluating the methods of treatment, effluent disposal, and sludge management. Exhibit 8 summarizes available information on wastewater characteristics for Beirut.

Effluent Discharge Standards

The Ministry of Environment had proposed standards related to the disposal of wastewater in the Mediterranean (Exhibit 9). These standards dictated the level of treatment required.
required and influence the treatment alternative to be implemented.

THE DECISION

Taking social, environmental, technical, and economic factors into consideration, the Council of Development and Reconstruction needed to decide on criteria for locating a treatment facility for the city of Beirut, determine the level of treatment, and select the final discharge media for the treated water. All those elements are part of a wastewater management plan for Beirut. What decision should the CDR make?

TEACHING NOTE

Case Objectives

Upon completion of this case, students should be able to:
1. Discuss environmental impacts of uncontrolled offshore disposal of wastewater.
2. Identify site selection criteria for locating a wastewater treatment plant.
3. Define and evaluate alternatives in wastewater treatment and discharge.
4. Define and assess priority design and planning criteria in wastewater management.
5. Select and develop a design for wastewater treatment processes.

Uses of the Case

This case study is intended for senior undergraduate and graduate level students in environmental engineering and science. Design questions are intended for students with the appropriate technical background, particularly in wastewater treatment processes. Students will use decision-making skills to integrate primarily the scientific and social components of the case. The case, based on country-specific data and events, provides students an opportunity to conduct a preliminary evaluation of a wastewater management plan in a developing and high-growth coastal city, even though there may be insufficient data. Therefore, students often misunderstand that the case will provide them with all the needed information—this belief should be diffused early by stressing the need to search for additional information from various literature sources, local firms, or even field surveys to collect their own data. In evaluating the information, students should learn to evaluate the reliability of the data and their sources. The importance of social and political considerations in deciding community issues are emphasized in the fact that even in the presence of public opposition for certain developmental projects, governments may find themselves forced to comply with international obligations, particularly when economic factors are at stake.

Implementation of the Case

The case was successfully tested in a senior-level undergraduate course on wastewater treatment processes at the American University of Beirut. The class was composed primarily of civil engineering students. Invariably, the feedback of students was positive and in fact, their reports were used to improve on the case and refine certain questions. While case studies can be implemented in a variety of ways in a classroom setting (Herreid, 1994), the implementation should be appropriate to the background of the students and the objectives of the course. The case can be assigned as outside reading followed by a general class discussion of the case issues and the decision that needs to be reached with the corresponding justification. Written reports could be required for grading purposes. After instructors respond to these reports, students’ answers can be discussed in class in the context of actual events and the final decision that has been planned or was implemented. Another approach is to have the case read in class (only for a 3-h class that is offered once a week, otherwise the case would be too long for a 1-h session) followed by either small group or whole class discussion of all or selected questions. While the latter approach requires the least amount of class time, it also provides the least chance for students to reflect on the issues of the case. Some socially oriented questions lend themselves to role-play, whereby students assume the role of the opposing or supporting views of the community. Role playing offers the advantage of practicing public speaking and increased awareness of socio-economic constraints and hidden agendas. Other questions can actually be asked in an examination to stress to students that they may often be faced with situations where they have to address certain issues in real-time. Note that some questions can be eliminated from the case study if the course is not intended to teach students about design of wastewater treatment facilities. Examples of wastewater treatment textbooks that might be used in conjunction with this case include Metcalf and Eddy (1991) and Crites and Tchobanoglous (1998).

DISCUSSION QUESTIONS AND ANSWERS

1. Identify the potential adverse environmental impacts associated with open-sea disposal of untreated wastewater.

Seawater is typically in a state of ecological balance providing a harmony between plant and animal life with considerable interdependence among various life forms (Exhibit 10). The introduction of excessive quantities of pollutants may disturb this balance and result in toxic concentration levels for specific life forms. Excessive quantities of organic material might also result in rapid bacterial growth, which leads to the depletion of dissolved oxygen resources (<2 mg/L compared with 5–7 mg/L for healthy conditions) and results in the death of fish and plants. In addition, direct discharge of wastewater into the sea would result in excess suspended solids on the seawater surface and sedimentation on the sea floor. Suspended solids at the surface block out energy from the sun, thus affecting the carbon dioxide–oxygen conversion processes (photosynthesis), which is vital to the ecological cycle. Long-term sedimentation of the sea floor hinders navigation near the shoreline and may require frequent dredging. Last but not least, discharge of untreated wastewater presents a serious health hazard through direct exposure (bathing) or consumption of fish, not to mention its effects on recreational activities (aesthetics, offensive odors).

2. Identify a set of priority design/planning criteria in wastewater management.

Selection of the appropriate technology for treatment and disposal of wastewater requires an in-depth evaluation of the objectives that are to be achieved.
Subject to technical and economical constraints to be considered in the evaluation of alternatives, the general objectives outlined below could be regarded as guidelines set for process selection:

- Domestic water sources—aquifers, springs, wells, or surface water—should be protected against contamination by wastewater.
- Irrigation of agricultural lands by wastewater reuse and utilization of treated sludge as a soil conditioner should be promoted where cost-effective, but only when pathogens have been effectively removed; pollution of irrigation supply sources by inadequately treated wastewater should be prevented.
- Conditions for water-based recreation (swimming, boating, and fishing) will be enhanced by improvements in water quality and control of marine discharges.
- Water conservation by means of irrigation reuse, aquifer recharge, or industrial reuse of treated effluent should be practiced where it is cost-effective and water resources are otherwise inadequate.
- Compliance with the Mediterranean Pollution Commitments.

3. Identify criteria through which you can consider existing offshore outfall as an adequate treatment option. A suitably designed outfall should ensure effective dilution at a distance away from the shore to:

- Comply with set criteria for bacterial concentration in recreational waters and shellfish growing areas.
- Prevent any sensory offensive conditions and identifiable waste materials from being present at waters used for recreational purposes.
- Maintain a dissolved oxygen level of $\geq 5$ mg/L outside of the zone in which the sewage plume undergoes initial dilution.
- Prevent the presence of persistent, toxic compounds by controlling them at the source.
- Prevent accumulation of solids on the sea and prevent anaerobic conditions from prevailing.
- Prevent the presence of high concentrations of nutrients.

4. Discuss the different levels of wastewater treatment and effluent discharge alternatives with corresponding advantages and disadvantages. In coastal areas, the ultimate disposal of treated wastewater is primarily to the sea. Pre-treatment of wastewater before discharge into the marine environment through ocean outfalls could be performed with different degrees of complexity (preliminary, primary, secondary, or tertiary). Aquifer recharge is a possibility, which can be considered to alleviate the problem of seawater intrusion into coastal aquifers resulting from indiscriminate tapping into these aquifers. Wastewater reclamation and usage for irrigation of agricultural land is another possibility for effluent management. Thus, the various alternatives that can be considered for wastewater treatment and disposal alternatives include:

1. Maintain the same offshore disposal method.
2. Preliminary treatment and offshore disposal.
3. Primary treatment and offshore disposal.
4. Secondary treatment and offshore disposal.
5. Secondary treatment and land irrigation.
7. Tertiary treatment and aquifer recharge.
8. Tertiary treatment and municipal reuse.

Each alternative is associated with a series of advantages and disadvantages as presented in Exhibit 11, which also provides a description of the various treatment options.

5. What is the general feasibility of these alternatives? As a general rule, it could be stated that the more complex the treatment the shorter the outfall. However, this is not always true. The level of required treatment, the availability of suitable onshore and offshore conditions, the magnitude of the works and, most important, the economics are all factors that will have to be considered in evaluating the various alternatives. In Lebanon, a number of constraints, such as difficulty in finding suitable sites with ample areas for secondary treatment and limited financial resources available for initial investment as well as for operation and maintenance, basically narrow down the alternatives to no more than secondary treatment, all while minimizing the amount of surface area required.

6. What is a common problem with various treatment alternatives and how is it handled? Irrespective of the treatment alternative selected, sludge generation will remain a problem. Sewage sludge may be expected to contain, to some
degree, all the types of contaminants present in the raw waste. Many of these are toxic and some of them are concentrated in the solid fraction. Sludge treatment, besides its complexity, is a costly operation. Sludge handling techniques are directed toward reducing the moisture content and thereby the volume of the sludge. Methods of sludge handling include:

- Landfilling without any pretreatment
- Thickening (water content reduction)
- Dewatering and stabilization (biological digestion)
- Reduction (via open bed drying, burning, composting)
- Disposal (sea or land after treatment)

7. Select one alternative (justify your selection) and develop a preliminary design of the various components of the corresponding treatment facility (only for advanced students in the proper field). This question is suitable for senior-level civil engineering (or related field) students who have taken or are taking a design course in waste treatment processes. The process of selecting the most suitable alternatives must include a comparison of advantages and disadvantages (see Exhibit 11), an economic and feasibility comparative evaluation between the various alternatives, and the physical and resource constraints at the location of the planned facility. After the selection of an alternative, typical design parameters that should be defined include:

- Design life
- Projected population served
- Per capita water consumption rate
- Wastewater characteristics
- Effluent characteristics

The preliminary design should present a layout of the plant showing its different components (Exhibit 12) and calculations should be made to define the geometry (width, length, depth, diameter) of these components as well as their design parameters (hydraulic and solid retention times, removal efficiency of selected environmental indicators listed in Exhibit 9, quantity of sludge produced at the various system components).

8. What factors should the council consider in selecting the final solution? Economic feasibility and least amount of disturbance to the surrounding community to ensure public support are major factors that should be considered in selecting the final solution. Other factors include international agreements and potential pressure from international donors.

### Exhibit 11. Assessment of wastewater treatment and disposal alternatives.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Treatment description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain the same offshore disposal method</td>
<td>None</td>
<td>• Cheapest</td>
<td>• Significant environmental impacts as discussed in Discussion Question 1</td>
</tr>
<tr>
<td>Preliminary treatment and offshore disposal</td>
<td>Includes measurement and regulation of incoming flow and removal of large floating solids, grit, and perhaps grease. Typical utilities used at this stage include coarse screens, comminutors, grit and grease removal tanks skimming or vacuum flotation tanks, pre-aeration and equalization tanks.</td>
<td>• Lower cost and complexity of construction and operation • Provides a first step in reducing sea and coastline pollution problems particularly from large size solids</td>
<td>• Quality of effluent still does not meet discharge criteria and will continue to cause adverse environmental problems</td>
</tr>
<tr>
<td>Primary treatment and offshore disposal</td>
<td>Includes the removal of suspended solids. In addition to the preliminary utilities, it consists of clarifiers with mechanical sludge removal. It also includes chemical coagulation to remove finer and dissolved solids such as phosphorus.</td>
<td>• Cost remains low compared with later treatment processes • Improved quality of effluent</td>
<td>• Requires large areas for clarifiers • Requires mechanical equipment that need regular maintenance • Produces a larger volume of sludge</td>
</tr>
<tr>
<td>Secondary treatment and offshore disposal</td>
<td>Known as biological treatment and intended for the removal of soluble and colloidal organic matter, which remains after primary treatment. This treatment alternative is designed to maintain a large mass of bacteria within the system confines to biodegrade soluble and colloidal organic material. There are two main techniques to carry out this process namely the attached (sand or trickling filters, rotating biological contactors) or suspended (activated sludge) growth process.</td>
<td>• High-quality effluent that can be safely disposed of at sea • Removal of organic material resulting in a permanent solution for coastal pollution</td>
<td>• Expensive • Requires even larger areas for clarifiers and biological reactors • Produces even a greater volume of sludge • Relatively difficult to construct near residential areas because of potential odors • Requires skilled personnel for operation</td>
</tr>
<tr>
<td>Secondary treatment and land irrigation</td>
<td>Same as above</td>
<td>• Same as above • Effluents through the soil is very clean (almost equivalent to tertiary treatment depending on soil characteristics)</td>
<td>• Requires the use of large agricultural areas • May result in nutrients deposits in the soil, which may accumulate with time (phosphorus, nitrates, and heavy metals)</td>
</tr>
<tr>
<td>Secondary treatment and aquifer recharge</td>
<td>Same as above</td>
<td>• Same as above • May reverse the problem of seawater intrusion • Prevents the water table from dropping during drought months</td>
<td>• Requires pumping to recharge zones • Increased cost for injection wells</td>
</tr>
<tr>
<td>Tertiary treatment and aquifer recharge</td>
<td>Typically performed if the effluent is intended for domestic reuse instead of disposal. May include the addition of chemicals or complex biological activities and advanced treatment systems such as activated carbon and reverse osmosis. Removes excess nutrients and heavy metals.</td>
<td>• Produces high quality effluent which can be safely disposed of at sea, on land, or in ground water</td>
<td>• Most expensive • Requires large areas for construction • Produces large amounts of sludge • Requires the use of large amounts of chemicals</td>
</tr>
<tr>
<td>Tertiary treatment and municipal reuse</td>
<td>Same as above</td>
<td>• Same as above • Effluent can be used to make for predicted future deficit in water demand</td>
<td>• Requires large storage tanks • Sociocultural barriers to domestic wastewater reuse</td>
</tr>
</tbody>
</table>
in other economic sectors, ease of implementation, potential for expansion, and operation and maintenance.

9. Discuss the potential opinion of a community located along a coastal area with respect to encouraging the construction of a wastewater treatment facility. The answer to this question may vary among students depending on socioeconomic status of the student and the community. Students living in developing areas would likely agree with the view of the opponents to the facility that their community is more in need of hospitals, schools, and roads than a treatment facility. It is expected that they will be resistant to any international pressure and will perceive a right in continuing to discharge into the sea until the country can afford treatment plants. In more affluent communities, the perception will likely be the opposite, particularly for those who use the coast for leisure and tourism. Irrespective of their social background, many might be resistant because of international pressure, particularly when the latter is conceived as an obstacle toward industrial development and economic growth.

10. Who do you think should be responsible for deciding whether a treatment plant is needed, and if so, who should decide on the level of treatment or effluent discharge standards? While various entities may be identified including academicians, the government, citizens, or the industry, the discussion should be directed to examine why any group is more suitable than others and how they may differ in their opinions.

11. What did the Council decide? It is natural that in a class setting students will expect to hear the actual, final decision that may be considered the correct answer. In reality, there are often several solutions, particularly to a design case study. This latter aspect must be emphasized by the instructor to ensure maintaining the breadth of the discussion and avoid ignoring all but one solution, which may not even be the most appropriate. Upon the recommendation of several consultants, the council adopted the concept of secondary treatment and sludge component.

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