

# **A Model for Optimal Industrial Wastewater Treatment as a Tool for Managing Port Environmental Security and Sustainability**

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# Background

- Water contamination from industrial plants is a major environmental threat to industrial ports, causing discharge of toxic metals such as mercury.
- Industrial wastewater treatment can reduce the damage and reduce the cleanup costs of contaminated harbors.
- There are several different treatment methods of industrial wastewater, including:
  - treatment with activated carbons to remove mercury,
  - and high-rate anaerobic treatment systems to treat organic matter in the form of carbohydrates or proteins.



# Reuse of Industrial Wastewater for Irrigation

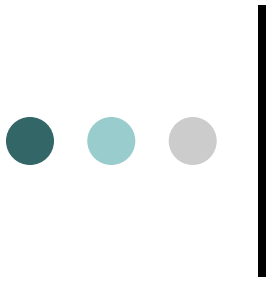
➤ Industrial waste effluents were found to be used as potential water source for irrigation.

(Akinyemi et al., *Journal of Environmental Extension* 2003)

➤ Industrial wastes affect crops:

➤ Small amounts of industrial wastewater results with high crop yields due to the highest mineral fertilizer.

➤ However, high amounts result in negative effects due to excessive N supply and to increased P<sup>3</sup> availability. (Mantovi et al. *Water Research* 2005).



# Cost-Benefit Analysis

- Choosing the optimal treatment level depends on the cost-benefit analysis.
- The cost of the wastewater treatment rises exponentially with increasing contaminant removal efficiency.



# Examples of Previous Cost-Benefit Analysis

➤ A mercury abatement cost curve- based on a simple cost minimization criteria.

Panero, Ph.D. dissertation. New School for Social Research 2005

➤ A cost optimization procedure to determine the optimal point of wastewater treatment.

Feng and Chu, *Process Safety and Environmental Protection* 2004

➤ A simulation/optimization model of multiple-pollutant wastewater management that includes industrial as well as municipal wastewater treatment.

<sup>5</sup> Carmichael and Strzepek, *Water Resources Research* 2000



# A Socio-Economic-Environmental Model

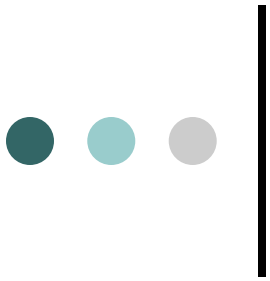
## **Purpose**

To determine the optimal level of industrial wastewater treatment

## **Considerations**

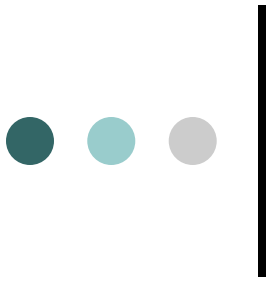
- The companies' profits
- The short-term and long-term benefit to society

The model uses nitrogen pollution in wastewater in Israel as an example.



# The Companies' Profit Function

- The individual factory wishes to maximize its net profit, disregarding the pollution effects.
- This profit is maximized at a given level of pollutants.



The individual industry's profit equation (1):

$$(1) V = P_q * Q - P_n * N_a - TC$$

Where:

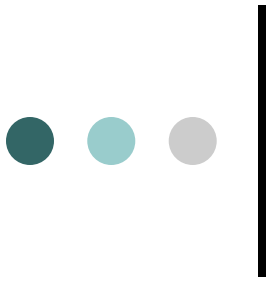
V is the net profit

$P_q$  is the price of the product

Q is the quantity produced

$N_a$  is the amount of nitrogen used

TC represents all other costs



The point of maximum profit will be reached by the amount of fertilizers  $N_a$ , as defined by

Equation 2:

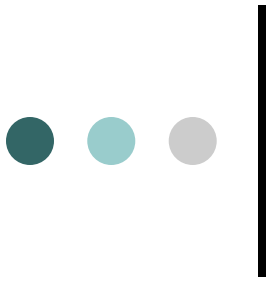
Where, price of fertilizer equals its value of marginal product

$$(2) P_n = P_q * dQ/dN_a$$



# The Benefit to Society Function

- The benefit to society depends on the effects of contaminated harbors on human health.
- In economic terms, this may be expressed as the cost of avoiding the damage by cleaning up the contaminated harbor.
- The model measures the cost of the environmental damage caused by increased nitrogen concentration in harbor water.



The national benefit includes the cost of the environmental damage caused by increased nitrogen concentration in harbor water, as shown in equation 3:

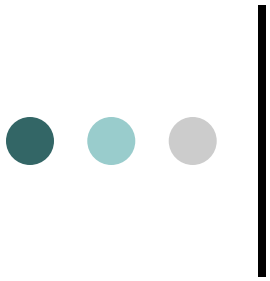
$$(3) B = V - D(N)$$

Where

B is the national net benefit

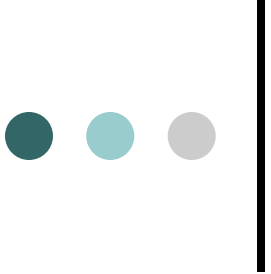
N is the nitrogen amount added to the harbor

D is the cost of the pollution change.



# Effect of Increasing Nitrogen Use

- Decreasing marginal returns to industry.
- Increasing marginal cost of harbor cleanup.



The optimum national gain takes into account the industrial profits as well as pollution prevention. It is reached at the point where Equation 4 is satisfied:

$$(4) P_q * dQ/dN_a = P_n + dD/dN_a$$

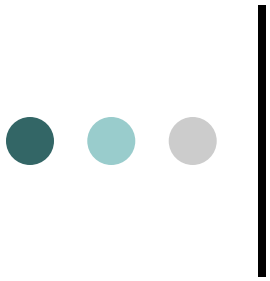


# The Point of Optimum Level of Pollution

The marginal net profit to industry  
from an additional unit of nitrogen

=

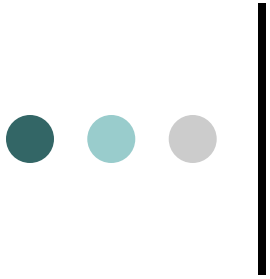
the marginal net cleanup cost of an  
additional unit of nitrogen



# Costs of Wastewater Treatment

## Prevention

According to the U.S. Department of Defense, the cost of industrial wastewater treatment varies between \$0.35 to \$1.40 per gallon of untreated water, but in some cases may go down to \$0.15 per gallon.



## Cleanup

- The costs of harbor cleanup depend on the level of contamination and the quality of the treatment.
- For example, cleanup of an oil spill into a port can vary between \$0.37 per gallon up to \$296 per gallon and more, in extreme cases.
- The cleanup of an oil spill in Huntington Beach in California in 1990 cost \$39.96 per gallon.



**Oil spill at La Hondura port (Spain) on the 27th of August 2004.**

Source: <http://www.atan.org/>

Nava Haruvy  
Venice NATO Workshop



# Reuse of Wastewater for Irrigation

- Wastewater may be treated and reused for irrigation of some crops, such as field crops, but not for raw-eaten vegetables.
- Enables to dispose of wastewater at lower costs than treatment for disposal.
- Provides a reliable and uniform source of water for irrigation.
- Serves as a source of macronutrients for fertilizing.
- Enables aquifer recharge.



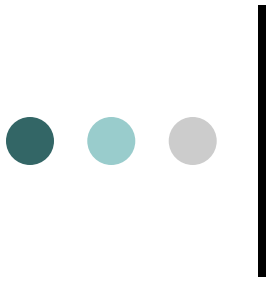
# Costs of Reusing Wastewater for Agriculture in Israel

- Economic benefit of aquifer recharge - \$0.03/m<sup>3</sup>
- The cost of water storage and conveyance - \$0.24/m<sup>3</sup>
- The marginal cost of the environmental damage caused by nitrogen leaching - \$0.10/m<sup>3</sup>
  - This includes the decrease in farmers' profits as a result of additional nitrogen leaching restriction of 1 kg/ha.
- The net cost is then \$0.31/m<sup>3</sup> (\$0.001/gallon).



# Conclusions

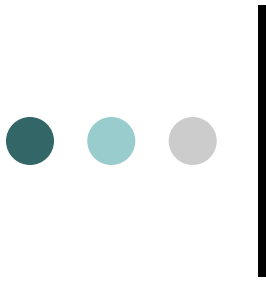
- The cost of wastewater treatment and reuse in agriculture is about equal, or slightly higher, than the cost of a simple cleanup of a concentrated spill.
- The cost of reuse, including water storage and conveyance, is much lower than most harbor cleanup costs, which generally involve more widespread water pollution.



# Conclusions

(continued)

For areas where agricultural cultivation is within close distance of the harbor, industrial wastewater should be treated to the level required for agricultural irrigation and diverted to agricultural lands.



# Thank you!

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