To Main Proceedings Document

Modeling and simulation of the effects of nitrogen waste on oxygen consumption in a Norwegian fjord

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Abstract

We consider a model of a small, industrialized community in the Sørfjord, a branch of the Hardangerfjord, Norway. For one century, waste from the factories has been dumped into the fjord. There has been a low rate of inflow of fresh seawater, and part of the fjord was previously known as the most polluted one in the world. Both the fjord and the factories are crucial for the sustainability of the community.

The effects of water pollution have been an important topic since pollution became a political issue in the 1970's. Data on the concentration of various chemicals has been collected to find how severe the environmental contamination is. There is, however, a lack of models that can transform data into relevant and coherent information and help us identify additional needs for data. The design of such a model requires the cooperation of experts from many different fields. In a system dynamics model, it is possible to combine knowledge elicited from various experts, so as to obtain a coherent theory of the dynamic physical and biological processes that takes place in polluted water.

Over the last years extremely low values of oxygen have been measured in the Sørfjord, and the life in the water is at the point of extinction. We have developed a model that identifies the effect of nitrogen being disposed from one of the local factories, and how the resulting process consumes large amounts of oxygen through a complex biological process. The model incorporates the expert knowledge of physicists and microbiologists on the life cycle of chemical components and associated bacteria, and how their effects are influenced by the inflow and outflow of water.

Introduction

For the past couple of years, the oxygen level in the Sørfjord has been at a critical low level. This may be caused by a number of oxygen consuming factors, such as chemical and biological transformation processes resulting from disposal of nitrogen by the factories into the fjord, sewage from the local town, and fertilizer runoff from farms. The water exchange rate also varies greatly, causing a varying inflow rate of oxygen. Both the fjord and the factories are crucial to the sustainability of the community.

The serious pollution problem in Sørfjorden has raised a significant interest among researchers, and the fjord is part of a national pollution surveillance program. The problem, however, seems to be that there is a vast amount of data that no one quite know how to handle or interpret. Through the use of system dynamics, we will capture some of the complexity of the fjord structure that causes the varying oxygen levels, and incorporate some of the data that has already been collected. The model will give us insight into the structure of the fjord and the resulting development of the physical and biological environment over time. The model will then be used as a tool to develop and test strategies in order to improve the oxygen level in the fjord, and also find out which data that must be gathered to validate the model. The model and the model development process will enable the decision makers to gain a better understanding of the system, and factors that determine its dynamics. In addition creating a better awareness of the problem addressed in the fjord.

The factories possess an assortment of data about waste that has been discarded into the fjord since the pollution started in the beginning of the century. By gathering these data and incorporating them into one model, we may obtain a more complete picture of the situation, and, thereby, the effects on the oxygen consumption. The decision makers at the factories are going to make decisions based on the model, and it is therefore important that they participate in the development of the model. They will then obtain a better understanding of the system they make decisions for. The model will also be developed in collaboration expertise from different scientific disciplines, such as biologists, chemists and physicists. It may often be difficult for researchers to get a clear picture of the system, because they typically have an overview of their own, limited area of interest. By mapping this knowledge onto a single model, it may be easier to obtain an overview of the system, and to understand more about why the system behaves the way it does. Specialists may also understand better how their research area is related to the research areas of other scientists investigating the system.

Pre-project

System dynamics has not typically been used to model this kind of problem. We therefore carried out a short pre-project in December 1999 in order to find out whether system dynamics is a suitable method (Hervig and Viste, 1999). We modeled the chemical reactions causing oxygen consumption resulting from DCD waste from Odda Smelteverk. Throughout the process it was made clear to us that this was a problem that both decision makers and scientists were interested in, but that they lacked a common model in which they could organize. Decision makers revealed to us that no one really knew how a change in pollution strategies would affect the system. There was especially a problem about the time horizon in question and how large the effects of new policies would be.

System dynamics is also a tool for gathering information about the system. One of the major problems in dealing with environmental issues is the clear division between lawmakers, decision makers and experts, and the knowledge of the system often involves people with different backgrounds. The rules for how much and what kind of waste a factory can discharge is set by the State Pollution Authority (SFT). This is a governmental agency that surveys and informs about environmental development, and uses its authority in order to sustain and improve the environmental quality through regulations and controls (http://www.sft.no, 27.04.00). The factories must follow these rules, and must make their own decisions about how to meet the criteria. The decision makers at the factories do not have enough expert knowledge to address this problem, and must therefore hire experts from various environmental institutions to help them make the decisions. These services are expensive, and decisions may have to be made without the decisions maker knowing precisely hot the system will react. The researchers that are hired by the factories also hold a variety of perspectives.

The model

The model represents a system where nitrogen-bearing waste causes an excess consumption of oxygen in the fjord. This is a complex system with biological, chemical and physical processes. The nitrogen, in different forms, is food for different bacteria, and in the process of utilizing the nitrogen they consume oxygen. The main parts of the model are a couple of population models for bacteria and a water exchange component. (Simplified CLD in Fig. 1) A lot of different factors are influencing the consumption of oxygen, but the supply of nitrogen and the access to oxygen is the main factors.

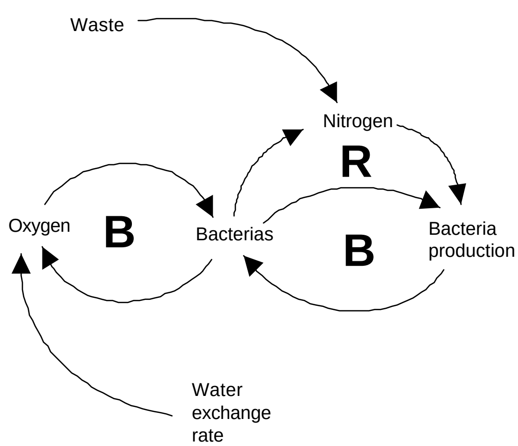

Fig. 1

The nitrogen comes from a wide range of different sources, and how it influences the system depends on the form and location of the disposal to the fjord. One of the sources is diffusion from the sediment. Waste from the factories has been dumped into the fjord, and the leakage of nitrogen will continue for years after the dumping comes to an end. This represents a major delay in the system. The supply of oxygen is mainly caused by the water exchange. Fresh water with a high oxygen level replaces the old water. The velocity of the water exchange in the fjord states supply of oxygen. Water coming from different rivers around the fjord does also contribute with oxygen, but only to the topmost layer. This layer contains brackish water with a low salinity, and does not mix with underlying layers.

There are big differences between the conditions in the surface-layer and the deeper water-layers in the fjord. Likewise there are differences between the inner part of the fjord and further out. To get a realistic view of the system it is necessary to build a model that includes these differences. This means that because of the water exchange, and the fact that the fjord is divided into layers that just have small influence on each other, different part of the fjord has to be modeled individually and put together in a matrix. The oxygen level is different in areas around the disposal points then in other areas of the fjord. Each model represent a physical part of the fjord, and output from a model is used as input to the neighbor models.

Objectives

One of the objectives of the project is to create better communication between decision makers, scientists and government officials through the understanding of a common model. Part of the problem that exists today is that there is no common model that incorporates the different views that the various decision makers have of the system. Due to the complexity of the system it seems like no one actually has an explicit model of the system. If the parties make conclusions and decisions based on different models, it will be difficult to cooperate, and even discuss which decisions to make, or why one got a particular result. Decision-making based on different models may create confusion, and the reason one does not get the results one wants may be that decisions are made based on conflicting premises. According to Andersen “if there is no agreement on how to do things and different people in an organization do things differently, this may negatively impact the performance of the system” (Andersen, Richardson, Vennix, 1997). In our case we are dealing with a natural system, and the various parties will only have the opportunity to impact the system by varying input. However, the input may vary with the perception one has of how it will effect the system. The goal is for the decision makers to communicate based on a common model. This model can be seen as an agreement of what the structure of the system looks like, and will make it easier to discuss problems on shared premises.

An additional important result of the project however, will be the learning process that takes place through the development of the model. Often “most of the learning takes place in the process of building the model, rather than after the model is finished.” (Vennix, Andersen, Richardson, 1997). Through working on a common model the participants will be able to work together to solve a problem that they all have in common. Scientists will learn more about their own area of interest, and will be able to see how it relates to other research fields. Already through our first conversation with researchers at the Norwegian Institute of Water Research, we discovered that the use of system dynamics modeling helps focusing on questions that may be relevant for the problem. This helped focus on which areas there were gaps in their understanding of the system.

References

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