DECISION SUPPORT SYSTEM (DSS) FOR MANAGEMENT OF PCP MIGRATION IN THE ENVIRONMENT

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Abstract

This paper describes a Decision Support System (DSS) concerning pentachlorophenol (PCP) migration in the environment. The principal objectives of the DSS are to assist managers in siting of PCP-treated poles in the Hydro-Québec system and the storage areas and in the treatment of customer complaints. Four mathematical models are included in the system: a model for predicting migration in and on the immediate surface of the pole, a model for predicting migration in the soil, a model for predicting runoff and a model for predicting migration in groundwater. Factors influencing the migration of PCP in the environment are discussed.

Résumé

Hydro-Québec développe actuellement un système interactif d'aide à la décision (SIAD) concernant la migration du pentachlorophénol dans l'environnement. Les principaux objectifs du SIAD sont de fournir une assistance aux gestionnaires concernant la localisation de poteaux traités au PCP sur le réseau et dans les aires d'entreposage ainsi que le traitement des plaintes des clients. Quatre modèles mathématiques de prédiction sont intégrés dans le système informatisé: un modèle de migration à l'intérieur et à la surface immédiate du poteau, un modèle de migration dans le sol, un modèle d'écoulement de surface et un modèle de migration dans la nappe phréatique. Cette présentation abordera les facteurs influençant la migration du PCP dans l'environnement.

Introduction

Hydro-Québec has over one million and a half treated wood poles located throughout Quebec. 95% of these poles are PCPtreated. Given the issues surrounding this wood-preserving agent, the Environment Division at Hydro-Québec set up a program of studies on PCP. The computerized system for evaluating the behaviour of this product in the environment is part of this program. The mathematical modelling includes, first of all, a description of the various physical and chemical phenomena underlying the migration of PCP. A number of Hydro-Québec and external specialists participated in the development and validation of these phenomena. Laboratory experiments aimed at quantifying and supplying the input for the models are currently underway. These experiments will form the subject of a separate presentation.

Structure of the Modelling

The issue of PCP migration is not a simple one. This is why we will tackle it in a modular fashion. We will subdivide it into five blocks (figure 1) as follows:

Block 1 represents the migration of the pentachlorophenol (PCP) on the immediate surface of the pole. Blocks 2 and 3 correspond to the migration in the soil with Block 2 simulating the migration in the immediate vicinity of the pole and Block 3 simulating the migration beyond Block 2. Block 4 represents the migration of the product on the surface of the soil, whereas Block 5, its migration in the groundwater.

Block 1

General Considerations

Block 1 is probably the most critical part of the modelling. In fact, there is no information in the literature to describe the behaviour of pentachlorophenol in a wood pole. This is why much time and effort were devoted to this first block so that the phenomena involved could be properly understood. The various PCP migration processes can be represented as shown in figure 2.

When they come out of the plant, treated poles contain PCP and oil. During the storage period, a certain amount of these products leaves the poles and disperses in the environment. Thus, when they are installed, the poles contain a certain amount of oil and PCP which varies depending on the storage time. In addition, these products are not uniformly distributed throughout the pole. The depth of treatment of the pole is higher at both ends. Thus, the initial quantity (Qi) is a function of the storage time and longitudinal distribution of the PCP in the pole. It is this quantity that is used as the starting quantity for the modelling.

The oil and PCP exudes from the pole to migrate in the environment. The poles sweat to a certain extent. In the aboveground section, this sweated quantity (Qrh(air)) can migrate by gravity (Qg) along the pole or be carried by the precipitation (Qp). Depending on the type of soil, the oil and PCP solution can accumulate or spread on the soil surface (Qs) or penetrate the soil to possibly reach the groundwater. The products in the buried section of the pole (Qrh(soil) and Qrv) can migrate immediately. Two vehicles for the PCP are being considered, namely oil and water. The mathematical model for Block 1 will therefore be an empirical model based on laboratory experiments. With each iteration of the model, a mass balance reading is taken.

Migration Factors

Supplier. Each company has its own treatment process. Since Hydro-Québec purchases most of its poles from two suppliers, namely Domtar and IPB, these are the two types of poles that are considered for the laboratory experiments.

Wood species. The core/sapwood ratio differs from one variety to another. Since the sapwood portion is generally completely treated, the quantity of the products (oil and PCP) varies depending on the variety being considered. Also, the object of future laboratory experiments will be to show whether the wood species react differently to the factors considered.

Dimensions of poles. The quantity of the product that remains in the poles varies according to their height and class. Different dimensions may cause different hydrostatic pressures. Some laboratory experiments will study the effect of the size of the poles on the quantity of product that will migrate downwards within the pole (flow) as shown in figure 3.

Temperature. Temperature is a major factor that influences the behaviour of the treatment solution. In fact, the higher the temperature, the more likely the pole will sweat. This implies that there will be more product on the surface of the pole. The current results show that the product loss from the surface of the pole is notable but only to a very shallow depth. Over the years, the concentration of oil and PCP tends to stabilize nearer the core.

Precipitation. The more intense the rain, the more oil and PCP will migrate to the soil. Precipitation with an alkaline pH will encourage the PCP to separate from the oil and mix with water. This implies that two vehicles for the PCP must be considered, namely oil and water.

Photolysis. This factor was not used for developing the model. In fact, the conditions required for photolysis to occur being rarely present, this aspect was eliminated.

Blocks 2 and 3

General Considerations

The migration of PCP in the soil is an ongoing process. It is subdivided into two blocks: Block 2 and Block 3. The reason for the subdivision is simply a question of computing time. The numerical model developed for blocks 2 and 3 is based on the Richards differential equation solved by the finite differences method. This method consists in subdividing a field into fairly large subfields. The smaller these fields, the more precise the computations but also the longer the computing time. Since there is more PCP, in its organic or aqueous phase, in the immediate vicinity of the pole, the migration of the product must be followed more closely and the blocks subdivided into smaller subfields. The boundaries of the area are arbitrarily set at a distance of 1m on either side of the pole and at a depth of 3m. However, these limits can be changed as the user wishes. This area limited to the periphery of the pole is called Block 2. The migration of the product in the soil beyond this area becomes Block 3, the subfields of which are larger. The current model is two-dimensional. However, it still does not take into consideration the migration of the PCP in water, since no transfer function has yet been determined. A three-dimensional model will be added to the system later.

Several types of soil occur often in the same environment. This is why it is possible to superimpose several layers of soil of variable shapes and slopes. Over a hundred curves used to determine the diffusivity in various soils are integrated in the model.

Migration Factors

Type of soil. The nature of the soil plays a leading role in the migration of the contaminant. Oil-PCP and water-PCP solutions will migrate more easily in granular soil than in clay. Certain types of soil retain PCP more easily than others either through adsorption or otherwise. Column testing will make it possible to evaluate the extent of this phenomenon according to the nature of the soil.

Precipitation. The frequency, duration and numbers of millimeters of precipitation and its pH will influence the migration of PCP. Precipitation will increase the migration of PCP through leaching. Moreover, an alkaline pH will encourage the PCP to transfer from oil to water. This transfer function will have to be studied in the laboratory.

Depth of water level. The depth of the water level will serve as the boundary for Blocks 2 and/or 3.

Block 4

General Considerations

The soil surface migration model will be a one-dimension model. It will only be used when the soil is impermeable or when the soil is frozen but not covered with snow.

Migration Factors

Nature of soil. The runoff will vary depending on the nature of the deposits. Oil-PCP and water-PCP solutions will migrate differently depending on the presence or absence of vegetation. No migration will be considered when the soil is covered with snow.

Topography. The topography will affect the speed of flow and direction of the contaminant.

Temperature. Having an influence over the viscosity of the oil, the temperature will have a definite influence over the migration of the contaminant.

Precipitation. The intensity and pH of the precipitation will affect the migration of the contaminant as in the other blocks.

Discontinuities. Discontinuities (lakes, rivers, gulleys, drains, canals, etc.) will affect the spreading and dilution of the solution.

Block 5

General Considerations

The model for migration in the groundwater will be a onedimension model. The input for this block will be provided by blocks 1, 2, 3 and/or 4 depending on the position of the groundwater. This model will only be activated when the product reaches the groundwater.

Migration Factors

Chemical properties of the water. The physical and chemical quality of the underground water will influence the behaviour of the PCP. In fact, certain substances may react with the PCP. The water's temperature and pH will control the possible transfer of the PCP from the organic to the acqueous phase. This aspect still has to be tested in laboratory experiments.

Hydraulic gradient of the groundwater surface. The hydraulic gradient of the groundwater surface will affect the speed of migration of the oil-PCP and water-PCP solutions.

Soil hydraulic conductivity and porosity. These two factors will affect flow velocity.

Operation of DSS

Given the considerable computing time required by mathematical models as a whole, one might think that the DSS requires a supercomputer. The system will, in fact, function on a microcomputer equipped with an 80386 processor with at least four megabytes of RAM and transputers. Consulting will be done in real time. Hydro-Québec already uses parallel processing in many other projects and will use this technique for implementing the DSS. Users will be able to perform simulations in real time, since the parallel processing will make it possible to produce on microcomputers performances similar and even superior to those obtained on supercomputers.

The DSS will allow use of a laser videodisk. This laser videodisk will, for example, allow users to visualize certain laboratory experiments or certain types of environments, and topographical, geological or land use maps. The weather conditions will be provided through a telecommunications system that will allow the user to link up with the various weather stations.

A program manager will be developed to activate the appropriate models at the right time. Thus, the model for Block 5 will only be activated if the contaminant reaches the groundwater. The runoff model will only be activated if the surface of the soil is impermeable.

Conclusion

The Decision Support System will first and foremost be a prevention and management tool. The mathematical models are not meant to be only a prediction tool for determining the migration of the PCP in the environment from a specific pole. In such a case, the initial quantity of product in each of the poles and the environmental and climatic conditions specific to each of these poles would have to be determined exactly. Average and extreme scenarios will likely be used for the simulations. Understanding of migration phenomena is at the basis of a good mathematical model. This is what Hydro-Québec is currently working on.

The modular approach used for developing the DSS will make the models easy to adapt. For example, other migration factors could be taken into consideration or the system could be used to check the migration of any other wood-preserving agents. In such cases, a few quantities would simply have to be redefined such as adsorption and transfer functions in the soils and certain experiments pertaining to Block 1 repeated.

Given that certain laboratory experiments aimed at validating the various phenomena are currently in progress, the system is not completely functional or validated yet.

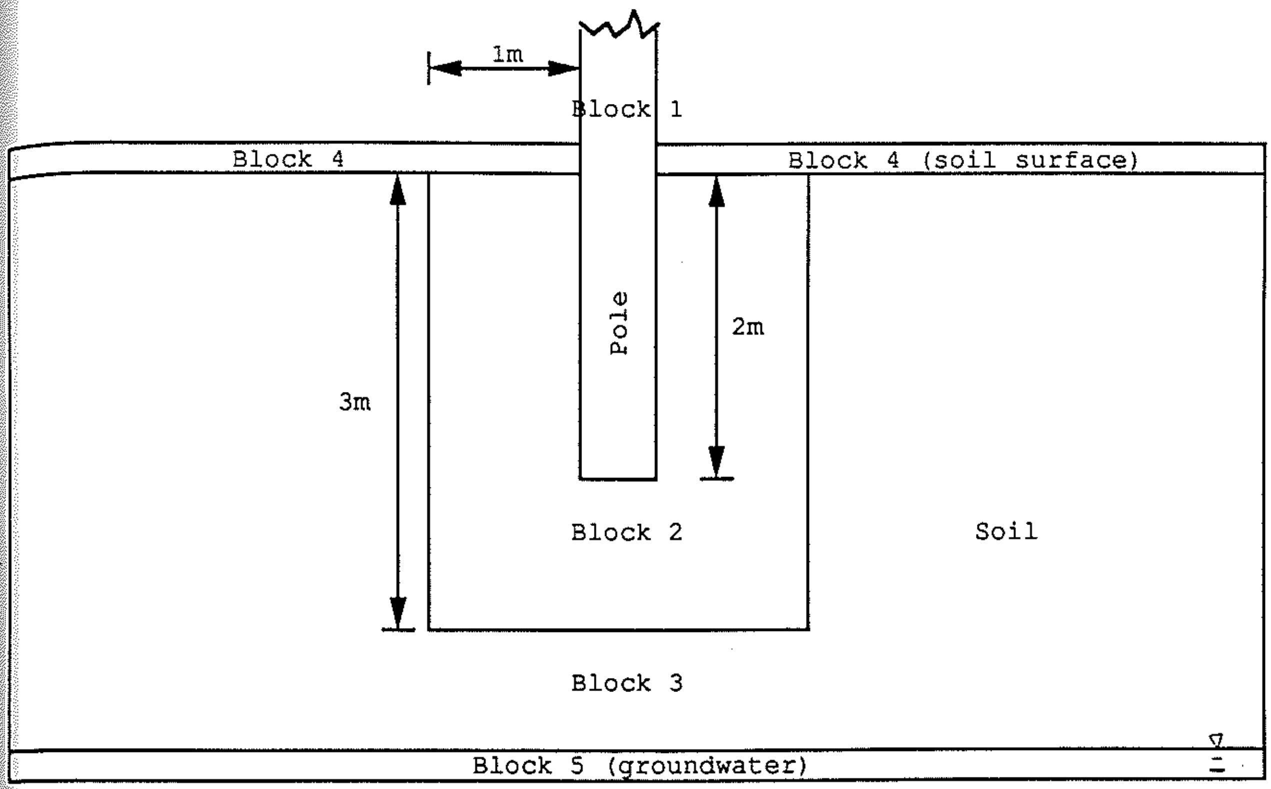

Figure 1. Schematic diagram showing the five blocks reflecting the PCP migration from treated poles.

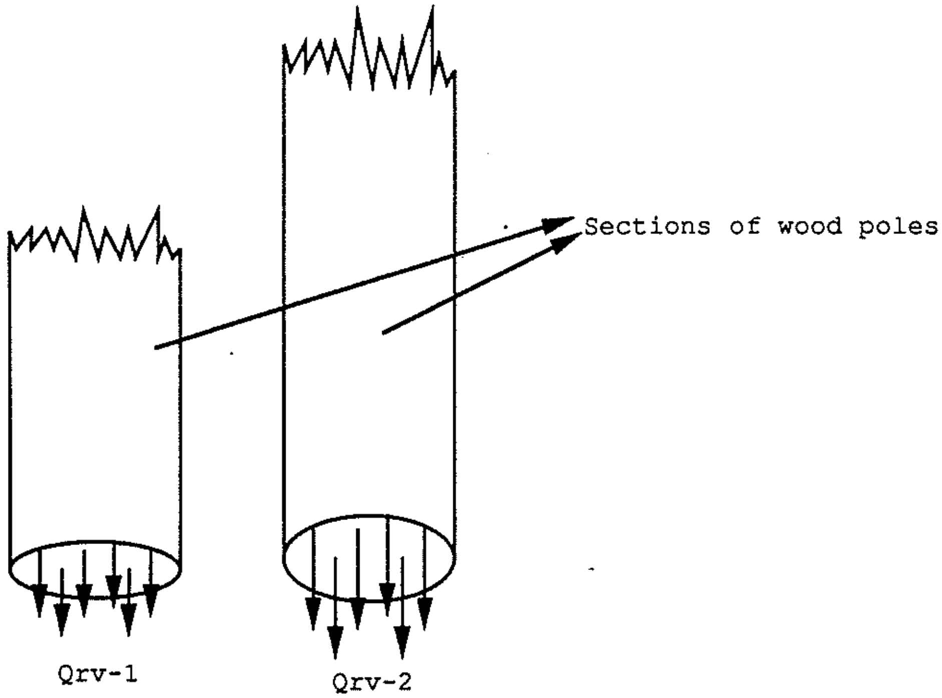

Figure 2. Schematic diagram showing loss of PCP in block1.

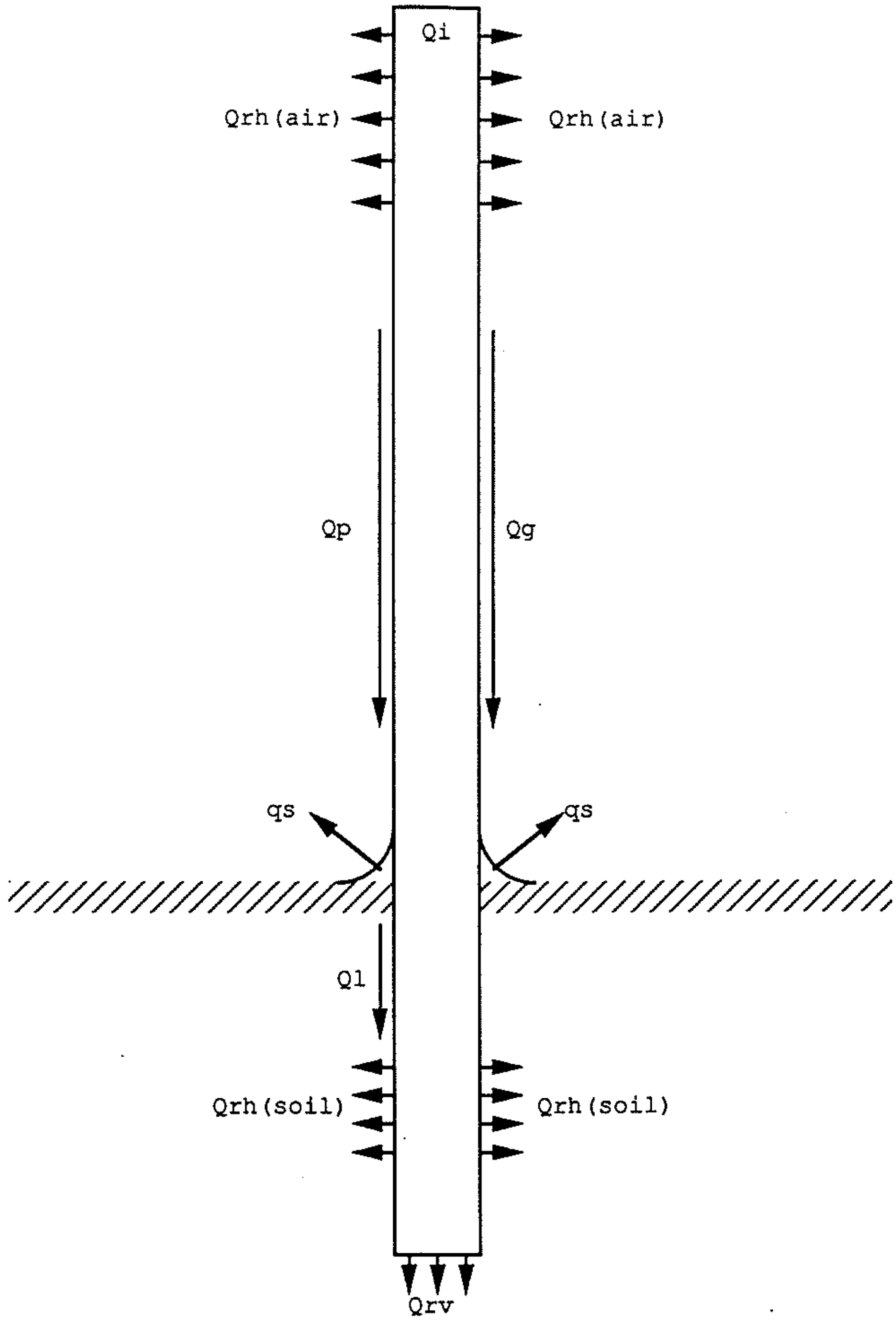

Figure 3. Schematic diagram showing the downward movement of pentachlorophenol in poles in service