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**INTERFACING A HYDROLOGIC MODEL
WITH THE RAISON EXPERT SYSTEM**

A.G. Bobba, D.C.L. Lam, D. Kay
and W. Ullah

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MANAGEMENT PERSPECTIVE

RAISON geographic information / expert system allows for the interactive analysis of spatial data related to water-resources investigations. A conceptual design for an interface between a RAISON expert system and a hydrological model includes functions for the estimation of model parameter values. Design criteria include ease of use, minimal equipment requirements, a generic data base management system, and use of a RAISON, micro computer language. An application is demonstrated for 3.90 km² of the North East Pond river watershed, NFLD, Canada. That performs automated derivation of watershed parameters for hydrologic modelling.

SOMMAIRE À L'INTENTION DE LA DIRECTION

RAISON, système expert et d'information à référence spatiale, permet l'analyse interactive de données spatiales liées aux recherches sur les ressources en eau. Une conception d'une interface entre un système expert RAISON et un modèle hydrologique comprend des fonctions pour l'estimation des valeurs des paramètres du modèle. Les critères de conception sont la facilité d'utilisation, un équipement minimal, un système de gestion d'une base de données générales, et l'emploi d'un langage micro-informatique RAISON. Ce système est appliqué aux 3,90 km² du bassin versant du lac North East Pond (T.-N., Canada) qui calcule automatiquement les paramètres du bassin versant aux fins d'une modélisation hydrologique.

ABSTRACT

The **RAISON** expert system allows for the interactive analysis of spatial data related to water resources investigations. A conceptual design for the interface between the **RAISON** expert system and hydrological model includes functions for the simulation of runoff. Design criteria include ease of use, minimal equipment requirements, a generic data base management system, and use of a micro computer. An application is demonstrated for Northeast Pond River watershed, Newfoundland, that performs to predict the runoff.

RÉSUMÉ

Le système expert RAISON permet l'analyse interactive de données spatiales liées aux recherches sur les ressources en eau. Une conception pour l'interface entre le système expert RAISON et un modèle hydrologique comprend des fonctions pour la simulation d'un écoulement. Les critères de conception sont la facilité d'utilisation, un équipement minimal, un système de gestion d'une base de données générales, et l'emploi d'un micro-ordinateur. Ce programme est appliqué au bassin versant du lac North East Pond (Terre-Neuve), afin de prévoir l'écoulement.

Introduction:

The use of a geographical information expert system in hydrologic modelling can be highly beneficial. To model runoff from a watershed, data need to be assembled that describe the physical characteristics of the watershed. The traditional approach to assemble this data involves considerable manpower for mechanically overlying and planimetering maps to generate the various required data sets. Because these efforts are manpower-intensive, sometimes requiring weeks or even months to assemble a model, variations in the hydrological modelling scheme are extremely limited. However, the use of a expert system can be a substantial timesaver that allows different modelling approaches to be tried. Further, an expert system provides a tool for looking at spatial information from a whole new perspective. It enables an investigator to selectively analyze only those data that are pertinent to a situation and to easily consider alternative approaches toward the analysis.

Unfortunately, the development and application of sophisticated expert systems are not trivial tasks. An expert system is a specialized technology requiring uniquely-skilled personnel to fully use its capabilities. To yield optimum benefits in hydrological modelling, its application needs to be made as easy as possible for a wide range of users. To maximize versatility, the conceptual design of any application tools should take into account the characteristics of various expert system software packages and hydrological models. A useful mechanism for the development of these tools is the micro computer language inherent in computer operating systems or in a comprehensive software package. Micro computer languages are easy to learn and they make developed procedures transferable between computers. Also, procedures are easy to modify or

customize to meet the specific needs of a hydrological model or a studied situation.

An interface between an expert system and a hydrological model, which are both relatively complex software systems, is being developed as an application of this technology. The TMWAM (Turkey Mercy Watershed Acidification Model) is a comprehensive runoff model of watershed hydrology and water quality. It is used throughout eastern Canada for watershed acidification assessments in a variety of hydrologic settings. Bobba and Lam (1985, 1990) discuss the development of the hydrological model and give an overview of its capabilities.

Conceptual design:

The interface being developed uses the micro computer language inherent in the RAISON software. The system is acronymed (RAISON) for Regional Analysis by Intelligent Systems ON microcomputers. Its design will provide a graphic, menu-driven interface between RAISON and the TMWAM model (Figures 1 and 2).

Its structure will be easily adaptable to various applications, including other hydrological models. The interface will be constructed around sets of analysis procedures with two primary functions. One set of procedures includes functions that estimate parameter values using model-independent data from RAISON. The other set of procedures includes functions, such as statistical analysis, that help the user to make decisions regarding the assembly of a watershed model for a particular

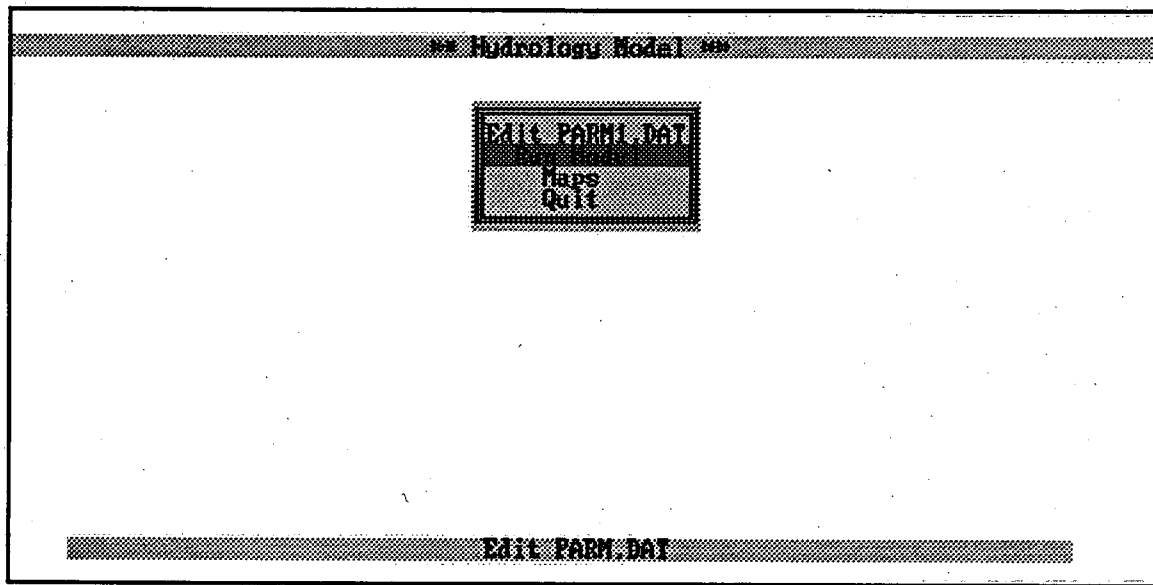


Figure 1: RAISON data base menu

basin. The interface will also incorporate a number of features that make it easier to use, including graphics operations, data search, and data enquiry.

Some criteria have been imposed on the overall design. It must be usable on micro computer with a minimum of specialized hardware. Also, existing software systems must be used when available. Existing coding and naming conventions and command syntax need to be used for both data and programs to conform with existing systems and to make future programming easier.

The RAISON expert system includes a data-base management system to handle the information that is associated with geographic coordinates. Some software packages link to proprietary data-base management systems as well. However, for the interface being developed, only the system

included within the RAISON software package is used.

TMWAM and other hydrological models can require several parameters. The RAISON system does not contain values of parameters, but rather physical data describing the watershed. Parameters need to be calculated from these physical data. The interface being developed looks-up the method to the procedure. Three general methods can be used: 1) parameter is set equal to a constant, 2) parameter is calculated using a simple algorithm, 3) parameter is determined by running a separate program.

Spatial Data Requirements for Runoff Models:

Simply stated, the central issue in runoff modelling is to establish a meaningful correlation between flow observed at a point along a stream, the amount of precipitation observed through time, and the surrounding character of the land. The presumption implicit in this report is that the use of more detailed spatial data can, with proper management, help to improve our understanding of certain hydrologic conditions.

Usually, simulation models employ a "lumped parameter" approach as described earlier (Bobba and Lam, 1985). The average or dominant response of an area upstream of the observation point is used to project estimates of flow given rainfall and other forms of moisture input through time. The flow actually observed before, during, and after a rainfall event (i.e., a stream hydrograph) is often used to verify and adjust the simulation model.

At present, virtually no simulation models have data management capabilities sufficient to handle the additional spatial detail contained in most available data sets. Basin boundaries are normally manually delineated and added as an additional parameter in the model. Summaries of vegetation, soils, and landforms are tabulated for the basin area. If new sub-basin analysis data are needed, the revised boundaries must be entered and the process repeated.

As design goals, a spatial data handling system capable of supporting hydrologic applications should be able to: a) subdivide a study area automatically into manageable working units; b) provide levels of detail on the characteristics of each unit; and c) repeat steps (a) and (b) as needed, in as flexible a manner as possible.

In contrast to the lumped parameter models, some researchers have employed fully distributed models (Solomon et al., 1969). That is, the study area is subdivided into a grid matrix. Each element has a unique value for each physiographic characteristic and is treated as a small basin of unit dimensions. The amount of runoff generated from each element in the matrix (and for each time increment) is routed through neighbouring elements until it reaches a route of established flow such as a stream. This approach seems favourable since much spatial data is handled in grid format. Due to the enormous computations involved, however, this approach has been limited in application to small watersheds. By comparison, the lumped parameter model is much more computationally efficient (Bobba and Lam, 1990).

As a compromise, many researchers advocate lumped parameter models (Alley and Smith, 1982;

Bergstrom, S et al. 1985, Bobba and Lam, 1990) that is, the study area is manually subdivided into sub-basin units that are small enough that the use of dominant characteristics does not involve gross simplification. At present, most distributed models use the same methods as the lumped parameter approach to estimate land characteristics, namely, "best guesses" or sampling procedures. The success of such an approach would seem to improve where the units could be labeled automatically with provisions for flexible redefinition.

A spatial data structure is defined as "a set of relations used to describe a geographical entity". A geographical entity, in turn, possesses "global properties, component parts and related...entities".

The Proposed System:

The initial model will not have the spatial data incorporated directly into the runoff model. Because a runoff model is not designed to handle spatial data, the spatial data will reside as a grid cell data file server on the same computing system as RAISON. This will provide access to the spatial data by users for analysis, down loading or displaying the grid data files. The connection to RAISON and its forecasting models will be two fold. First, the data set naming conventions used in RAISON will be used. The names will provide a user with information on the project name or coverage area (location or basin name) or both, basin name, data type (land cover, soil type, land use, snow cover, etc), the date data were collected, the resolution of the data, and other important ancillary information. The data will be stored in a RAISON format

generic enough to allow users to down load the data to a variety of processing and geographic information computer systems. The second connection is brought about by the development of a set of utility and analysis software packages designed to transform the data into the point summarized form required of the RAISON and runoff models. This software will transform the spatial data into a summarized point form and output it into a RAISON format thus making the output directly accessible by RAISON software and models.

Description of RAISON Expert System:

The RAISON expert system has been developed to run on a PC/AT microcomputer. Its development was motivated by the challenge to design a computer-aided support system to assess the water resources at risk impacted by acid rain in Eastern Canada. Soil maps and digitized deposition data were generated or converted as microcomputer files. Several simulation models had been implemented for microcomputers (Lam et.al, 1988) . While some data and models were still mainframe based, we made the decision to use microcomputers as our platform to deliver the system.

The RAISON expert system is written in the "C" language and contains five subsystems, all

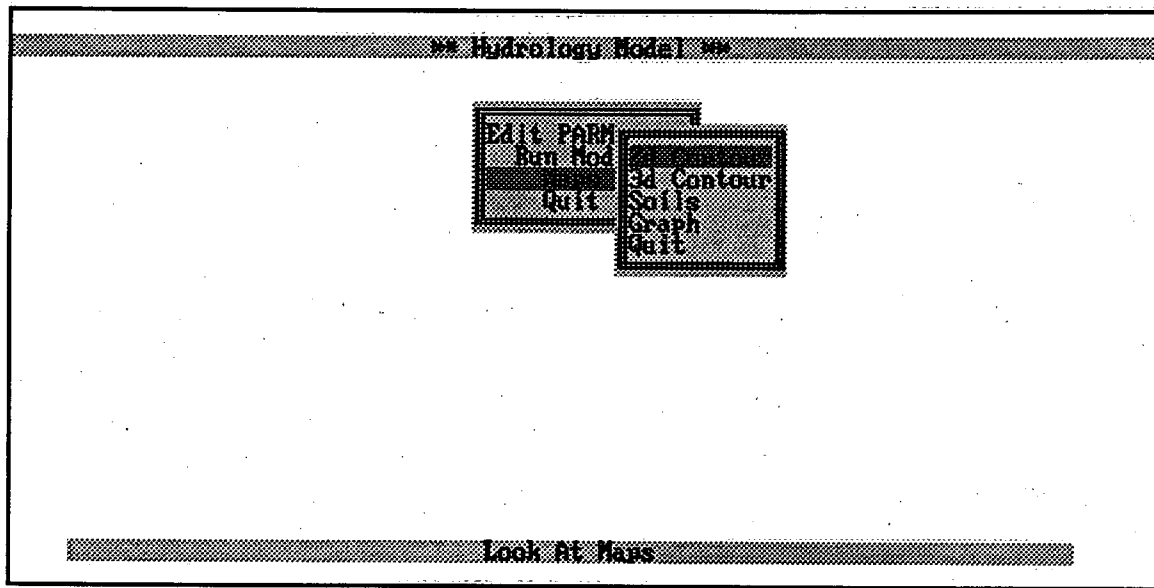


Figure 2: RAISON data base menu.

interlinked: map, database, rules, models and analysis. Each of these components can access the others, either through a menu or through the use of the **RAISON Programming Language(RPL)**. It has been used in various water resources applications including acid rain, mine effluent, rural potable drinking water, and state-of-management (Lam et.al.1988)

Application of RAISON Expert System:

The RAISON expert system has been applied to Northeast Pond River watershed which is located approximately 20 km west of St. Johns', Newfoundland, Canada. It has an area of 3.90 km² and geomorphological description is given in Table 1. The bedrock in the watershed consists of mafic and volcanic rocks. The bedrock is overlain by surficial unconsolidated deposits in thickness a meter or more. The overburden consists of olive firm, very stoney, sandy loam till derived mainly from grey slate. The top soil in the swamp area consists of fibrous and partly decomposed moss

peat mainly sphagnum mosses (Figure 3).

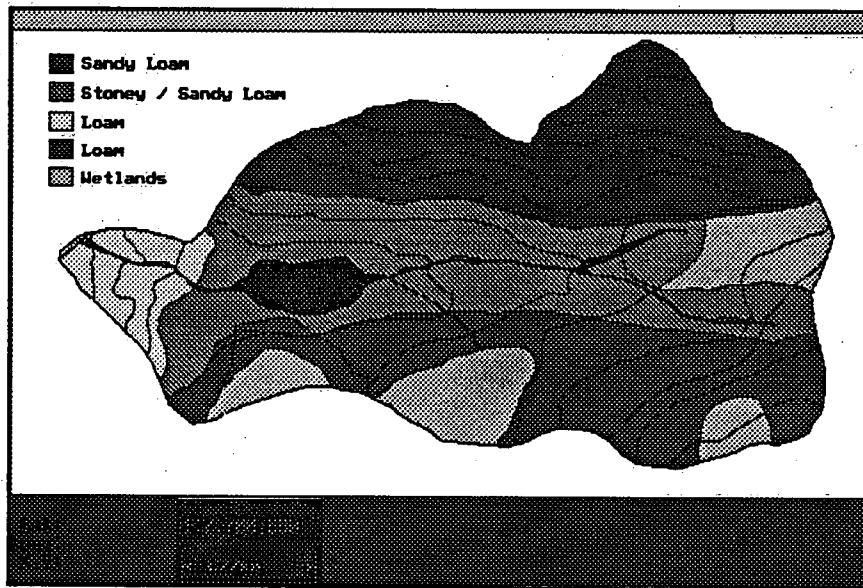


Figure 3: Two dimensional contour and soil map of Northeast Pond River.

The Map Interface:

Maps are entered into the **RAISON** system by means of digitizing the boundaries of the watershed, contours and different types of soils in the watershed. Figure 3 shows the Northeast Pond River watershed map with elevations. Figures 3 and 5 show the soil map of the watershed. A pull-down menu allows for the addition of new icons, access to the spreadsheet, data base, displaying the stream gauge, and printing the screen on either a conventional dot matrix printer or a colour printer.

The Database Management System:

Update Database			F1 - Help	F10 - Quit
Day: 2	Month: 10	Year: 1975		
MaxTemp: 18.900		PPT: 31.500		
MinTemp: 9.400		Flow: 060		
File: runoff.rdb Marked? No Record 2 of 3014				

File name added to file-list file.

Figure 4: RAISON data record.

The data is organized according to sampling stations (e.g. stream gage) within the watershed. Data entry and change are possible via the data base command in the pull-down manual. Figure 4 shows the options to create, update, link and import data. In the create mode, the user can specify a layout of his choice by defining the name of the variable, whether numeric or non-numeric, and the length of each record. Figure 4 shows an example of the data entered for weather of the watershed. By defining the appropriate layouts and entering the data accordingly or by importing previously processed files, one can easily install various data files in RAISON. One of the special features in RAISON is the ability to retrieve from any of these data files those variables that are of interest. For example, one can use the cursor to draw a polygon around those stations in the watershed that are of interest to the user and use the polygon command to retrieve the stream flow or weather data for further analysis on the spreadsheet.

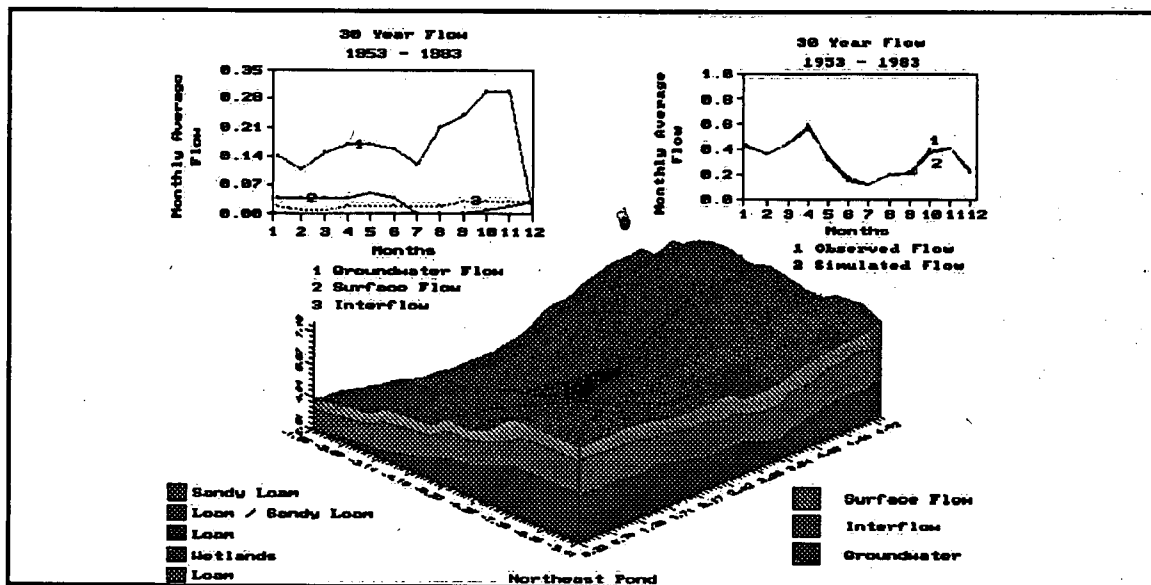


Figure 5: Three dimensional contour, soil map and hydrological results of Northeast Pond River

The Spreadsheet:

The spreadsheet in RAISON is designed to appear familiar to someone who has used the commercial variety. The options are available at the top of the spreadsheet, to access data files and worksheets, to calculate statistical means and medians or to compute according to a preset formula, and to backcolor stations or sub-watersheds according to some user specified functions. Some of the functions are specific to water quality due to acid rain problems (Lam et.al. 1989). While these simple mathematical operations provide fast and convenient results, more complex computations are best handled by programming. A new language, the RAISON Programming

Table 1A: Geomorphological Parameters of North East Pond River Watershed

Drainage Area (Km ²)	3.90
Lake Area (Km ²)	0.15
Swamp Area(Km ²)	0.67
Forest Area (Km ²)	2.94
Barren Area (Km ²)	0.14
Length of Main Channel (Km)	2.63
Slope of the Main Channel (%)	2.44
Soil Depth A (m)	0.15
Soil Depth B (m)	1.45
Soil Depth C (m)	2.75

Language (RPL), is developed for this purpose. This language is written originally in the C language and is easily used by programmers familiar with the BASIC Language. The program can be stored in a file and is accessible in the spreadsheet by the command, "runprog". It can also be run separately outside the spreadsheet. Typically, the RPL programs handle repetitive computations for a large number of data files, e.g. for all stations in a sub-watershed, or watershed.

The data required for the model are as follows: daily maximum and minimum temperature, daily precipitation amount (rain or snow), average stream flow data and hydrological model parameters.

The climate of the study area is dominated by the Labrador current which consists primarily of arctic waters. This current introduces relatively cold water to the area in spring and summer, but by comparison fairly warm water in winter. Hence the study area has a marine climate, characterized by short but pleasant summers and mild winters. The average temperature for the warmest month (August) varies from 13.5°C to 16.5°C over the study area, with the central part of the area being warmest and the coastal area coolest. February is the coldest month with average temperatures ranging from -4.5°C to -2.0°C. The precipitation, while fairly evenly distributed throughout the year, is heaviest during the winter months, May to September being the months with lowest precipitation.

A minimum set of RAISON coverage that includes land-use and soils data is required for the estimation of hydrologic parameters (Table 2). Soils are classified by hydrological properties and topography.

Table 2: Hydrological Model Parameters for Runoff Model

Infiltration (A-B)	0.40
Deep Infiltration (B-C)	0.035
Surface Flow(A)	1.400
Inter Flow (B)	0.400
Groundwater Flow	0.25

Table 3: Statistical evaluation of computed hydrograph with observed hydrograph.

	Rank Correlation Coefficient(r)	Rank Correlation Slope (s)	Mean Relative Error(e)	Coefficient of Efficiency (e)
Calibration Period (1954-59)	0.650	0.710	38.70	0.43
Verification Period (1960-83)	0.785	0.80	29.80	0.55

Results:

The TMWAM hydrological model was previously developed and calibrated for the period 1954-1959 and verified for the period 1960-1983. Conventional techniques were used to develop the model parameters. Three statistical techniques were used as indicators of the accuracy of the simulation. The computed hydrograph produces a satisfactory fit with the observed data. The statistical results are shown in Table 3. In particular, the episodic events during snowmelt for many years are accurately simulated as well as other episodes due to heavy rainfall. The

magnitudes at these peaks are also predicted reasonably well ($e=29.8\%$ with an improvement of 55% over the mean-as-model for the confirmation period. As we expected, infiltration coefficients are different from the top layer (A-B) to bottom layer (B-C). These differences are due to compaction of the till and different type of soils (Table 2)

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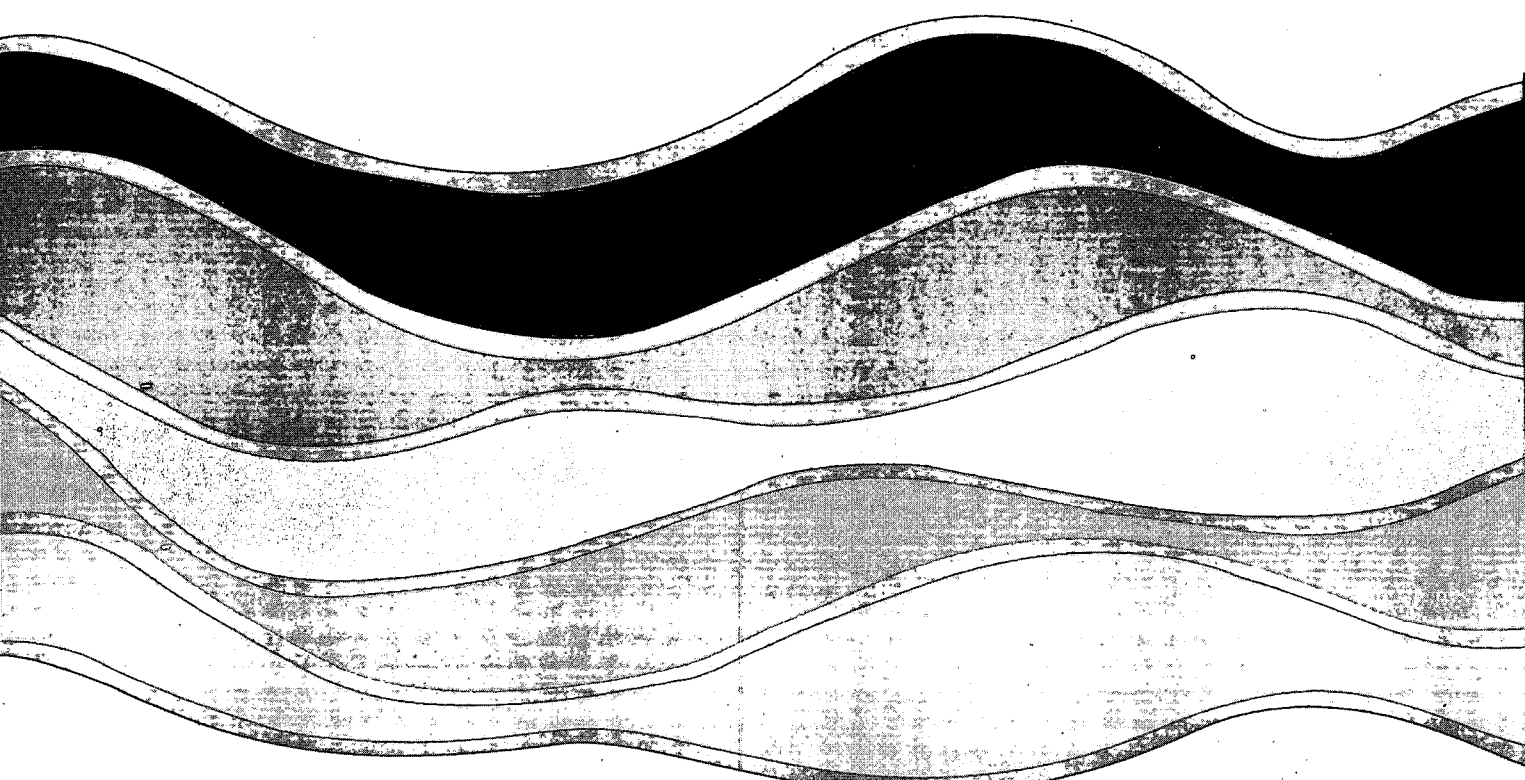
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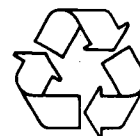
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