

GIS, URBAN DATA MODEL AND SYSTEMIC APPROACH FOR SUSTAINABLE MANAGEMENT OF URBAN DRAINAGE INFRASTRUCTURE

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ABSTRACT

The software tools available to urban drainage practitioners, more particularly in small and medium size cities, suffer, not only from a lack of data in terms of quantity and quality, but also from of an inability to lead to sustainable development of the infrastructures. They are in fact too "technically" oriented. In order to integrate the urban data with the drainage network environment, we propose a systemic approach and a data model for project design. We considered the drainage network as a component of the Drainage System which also includes treatment plants, specific infrastructures and alternative drainage techniques. This system, at the core of our study, interacts with four other systems reflecting the natural, artificial and economic environment of drainage. In this article, we present the principles of an approach which allows a multi scale analysis and we demonstrate its application, as well as its potential when used within the Noeux Les Mines (a small city located in the North of France) GIS (Geographical Information System) project framework. The project's objectives are to better understand the drainage networks of Noeux les Mines, to better represent them amongst the various components of the city and to ensure their sustainable development.

Key words : GIS, drainage, sustainable development, systemic approach, data model.

1. BACKGROUND

1.1 Drainage (storm and waste water) : context and stakes

Since the "tout à l'égout"(1) law was voted in France in 1884, the drainage techniques have increasingly evolved in order to meet the needs raised by a new context. The issues of wastewater collection and treatment, stormwater evacuation beyond the cities were successively approached. Even if wastewater management remains a main preoccupation for local authorities, the stormwater issue must not be neglected. Indeed, in order to cope with an increase of urbanization and pluviometric intensities, drainage managers and practitioners have to set up effective measures leading to a rational stormwater management strategy, not merely based on the "only network" concept, but rather on a "decentralized flow" concept. Rather than a systematic collection and evacuation through an underground network, this new principle proposes to stock, and/or infiltrate overland flow as soon as possible.

Based on a technological approach of drainage, a more global solution must be carried out, aiming at managing water at the basin scale. Therefore, drainage, as it is conceived today, should be in line with the sustainable development principles (Agence de l'eau, 1999). To this end, we should not only discuss drainage, but also "water management", a term which includes water supply, drainage and water treatment (Rossi and Motier, 2000).

1.2. Information systems and urban data drainage: inventory

The first software modules that have been developed using the GIS technology were primarily applications to support management operations, and more particularly the drainage networks

management (Didier and Bouveyron, 1993). These data-processing tools (that are now widely accessible) are often coupled with simulation and technical-economic assessment modules; so that they contribute to a better comprehension of the hydrological process, and provide a better support to the design and decision-making activities (Kukuric and Hall, 2000). Thus, certain research works have proposed a series of functionalities to contribute to decision-making process in this field (Dupont *et al.*, 1998). Other works have developed information processing systems which support an integrated approach to water management such as GIBSI (which allows the integrated management of basins using a computerized system) (INRS, 1999).

In small and medium-sized intercommunalities, the use of these tools is not yet widespread and even if they are set up, they are not really operational given that such intercommunalities do not always have the necessary strategies and resources for data capitalization. Moreover, if decision-makers and technicians have access to drainage networks data, these are often characterized by their diversity, incompleteness, uncertainty and inaccuracy, which do not facilitate the decision-making process (Cureaudo, Bergeron, 1998). In response to this context, our ongoing research work focuses on the modelling of hydrological data in order to facilitate the setting up of Urban Information Systems within small and medium-sized intercommunalities and to support the decision-making process.

2. OBJECTIVES AND WORK PLAN ADOPTED

The objective of our research work is to propose a data model of the urban drainage network and its environment, to support the development of drainage projects. The data model may also contribute to a better data management by :

- taking into account information about the data (metadata), such as the measurement accuracy, the date, the method of calculation, the parameters of the project etc.,
- adopting an efficient strategy of data capitalization,
- taking into account diversified data sources, geophysical data (such as services networks, roads, soil etc.), but also the socio-economic, demographic and environmental data,
- using different scales and definition levels for the drainage projects.

To achieve this objective, the work plan adopted is :

- to propose a modeling approach of the drainage system and its environment through its constitutive objects,
- to specify a data-processing platform for the model, based on the GIS and the Data Base Management System (DBMS) technologies,
- to implement and test the model on a real site.

3. MODELING APPROACH, PROCESSING AND TOOLS

3.1. Proposed systemic model

In order to carry out studies and analysis in the field of drainage, in particular those including environmental, social and economic aspects, it is necessary to have an approach that makes explicit the relations between the drainage components and their surrounding area. We have therefore proposed an approach to model the drainage network and its environment by defining a set of five interacting systems, the drainage system being the core one (Fig.1) (Top, 2005). The other systems are: the *Urban Infrastructure System*, the *Soil System*, the *Hydrological System* and the *Socio-economic Activity Zone System*.

The proposed model was built taking into account previous research works, combining specific data models aspects in a same framework : - drainage networks, specials works (Riosset, 1990) (Bourrier et

al., 1999) (Petit, 1999), - drainage networks, alternative drainage techniques and drainage basin (Barraud, 2002), - pipe environment modelling (Laffréchine, 1999), - morphology of an urban area catchment (Berthier, 1999) (Rodriguez, 1999), - buildings geometry with respect to the flooding problems (Hingray et al., 2000), - sub-soil and geotechnical environment [Boulémia, Masson, Henry as cited in (Top, 2005)].

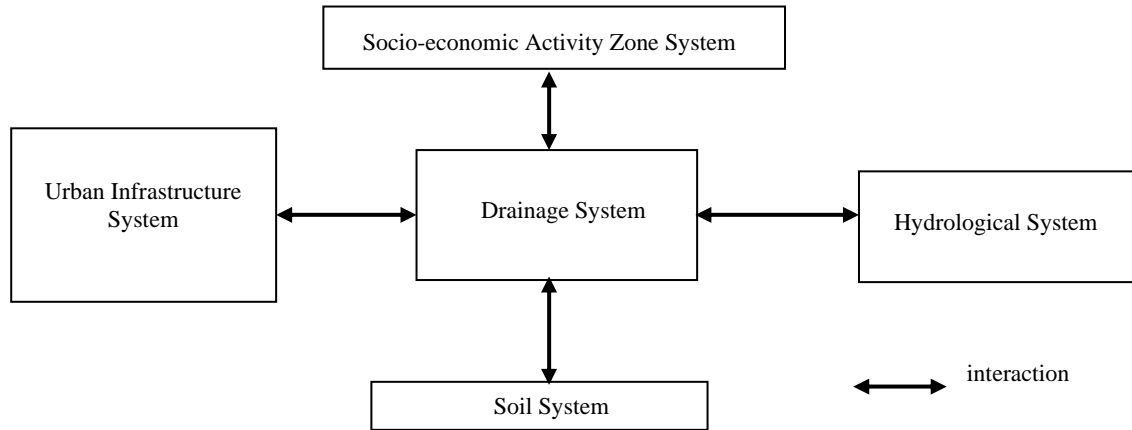


figure 1. Proposed Systemic model

We considered the *Drainage System* as a set of organized objects related to the evacuation and the treatment of waste and storm waters. The *Drainage System* is more particularly composed of the following objects: drainage networks, treatment plants, specific infrastructures and alternative drainage techniques.

The *Soil System* is described as a set of organized objects related to the soil. It is more particularly composed of the “*Soil Zone*”, the “*Soil Layer*” and the “*Surface Soil*” objects. They characterize the geotechnical, geological and sub-soil environment of the *Drainage System*.

We approached the *Urban Infrastructure System* as a set of organized objects related to the urban infrastructures. This system is more particularly composed of roads and other services networks (water, electricity and gas).

The *Socio-economic Activity Zone System* is represented as a set of organized objects related to the zones of activity in a city. This system characterizes the zones of social activities related to the human being (demography, housing, mobility of people, transport) and the economic activities areas (shops, industry, tourism etc.). The relevant objects are “*commercial, touristic and industrial areas*”, “*district*”, “*urban plot*”, “*buildings*”.

The *Hydrological System* is modelled as a set of organized objects related to water. It is, amongst other elements, composed of rivers, lakes, groundwater and drainage basins. This system is characterized by the “*natural*” flow of water and its quality.

3.2. Three scales to represent the system

We considered three scales to represent a drainage project : *macro*, *medium* and *micro* defined as following :

- the *micro* scale corresponds to the pipe level (few meters of pipe, or a specific infrastructure),
- the *medium* scale goes from a long pipe to a branch of the network,
- the *macro* scale is at the level of the drainage network (from a few hectometers to several kilometers).

We applied this principle not only to the *Drainage System*, but also to the four other systems. In table 1, we list some of the objects existing in the systems, distributed according to the three scales.

Representation scales System	Macro	Medium	Micro
Drainage system	e.g. Network, Sub-network	e.g. Part of network, Node, Branch of network	e.g. Pipe
Socio-economic Activity Zone System	e.g. City, Activity Zone	e.g. District	e.g. Urban plot, Building
Urban infrastructure System	e.g. Road	e.g. Path lane	e.g. path lane element
Soil System	e.g. Soil zone (geology)	e.g. Soil zone (geotechnics)	e.g. Soil layer
Hydrological System	e.g. Basin, Sub-basin	e.g. District sub-basin	e.g. Elementary sub-basin

table 1. Systems, objects and representation scales *macro*, *medium* and *micro*

3.3 Processing and associated tools

The development of drainage projects requires a study process which generally can be split into four phases : definition of objectives and needs, diagnosis of the system, development of scenarios and choice of solutions. Regarding these phases, the tools selected should make it possible to :

- characterize the drainage system and its environment (structural analysis),
- provide a diagnosis of the drainage system (functional analysis) in order to identify the priority areas and actions to be carried out,
- propose suitable scenarios,
- evaluate the impact of these scenarios on the hydrological system.

Thanks to their capability for spatial analysis and data modeling, the GIS and the DBMS are the appropriate tools to set up a data model and to carry out data processing as described above.

These two software tools, coupled with specific modules for simulation and multi-criteria analysis will make it possible to support the decision-making process (Consuegra and Crausaz, 1997). The application presented in the following paragraphs illustrates the implementation of the proposed model and gives some examples of data-processing using these software tools.

4. APPLICATION

4.1 Experimental site and objectives of the application

The experimentation of the model has been carried out on the site of the “Communauté de Communes de Noeux les mines et Environs” (CCNE). This intercommunality is located in the North of France. The CCNE is a public institution enabling co-operation among medium-sized cities. The CCNE gathers six cities, with a total population of approximately 18,000 inhabitants on 40 km².

The major problems that the CCNE is facing in terms of urban water management are the management of its drainage networks and the improvement of its drainage system performance with regards to hydraulics and environment. The drainage system of the CCNE mainly consists of combined networks. For its maintenance and development, one of the conceivable strategies would be to encourage the systematic development of alternative drainage techniques (e.g. roads equipped with water reservoir, water ditch). By intervening at the upstream of the network, the objective is to reduce the hydraulic load on the existing network, in order to limit the river pollution caused by the wastewater discharges after precipitation. This load reduction on the existing drainage networks would

also make it possible to increase the capacity to absorb the future development of the cities. At a first stage, the decision makers in the intercommunity (CCNE) wished to know in which areas the alternative drainage techniques should be used more advantageously. To refine the study, a hydraulic and hydrological assessment may be carried out to be able to estimate the quantities of run-off water, the capacity of the drainage networks as well as the quality of the water discharges. From this point, decision makers will then be able to decide precisely which techniques are to be adopted for each area.

The first application of the model was therefore to identify the preferential areas for the establishment of alternative drainage techniques. A sector of the Noeux les Mines area was selected for this first test. This site comprises three socio-economic activity zones.

4.2 Implementation of the model and its data processing principles

The software platform used was established using ARC-VIEW® GIS-Software and ACCESS® DBMS.

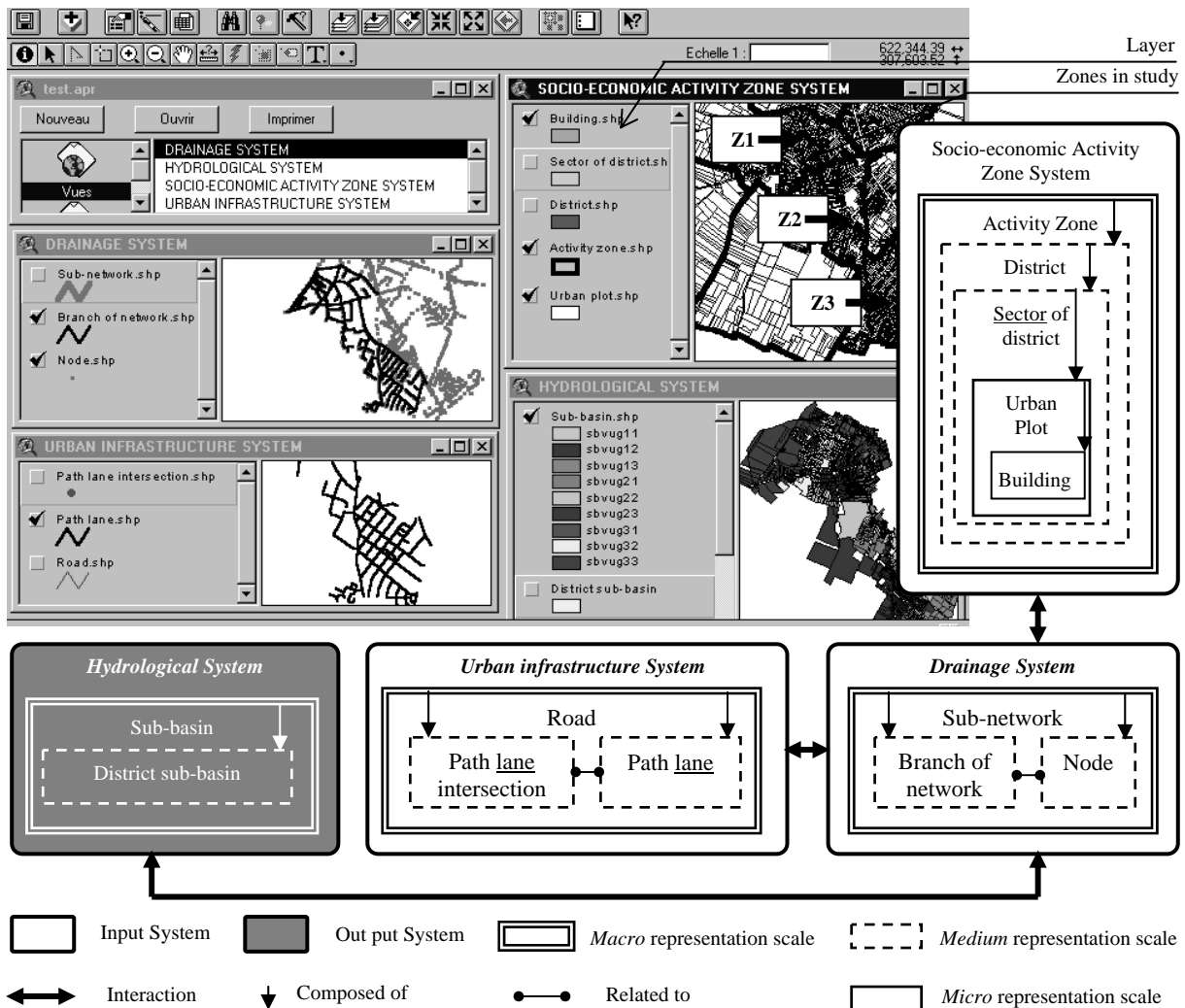


figure 2. Extract of the model and GIS translation

The CCNE provided us with the most accessible and available data at the time of application. The digital data used came from :

- the "BDTOPO" database of the National Geographical Institute (IGN),

- the plot map of the National Agency for land property,
- the drainage network.

For this application, we only entered a part of the model on the GIS software : the data for the *Soil System* were not incorporated because at this stage they are not essential to resolve the problem set in our objectives. It is only in a further step of the design process and the choice of techniques that the detailed soil characteristics will become a determining factor.

The geographical view in figure 2 (left side and center) shows the information layers for the “*Socio-economic Activity Zone System*”, the “*Drainage System*”, the “*Urban Infrastructure System*” and the “*Hydrological System*”, located on the map of “Noeux les Mines”. Considering our model, the systems are composed of objects sets, gathering data which we have translated by a set of layers associated with data tables in the GIS. At the top right corner of the geographical view, the thick lines mark the limits of the three activity zones Z1, Z2, Z3. In the conceptual diagram of the model (on the right-hand side and at the bottom of the figure), the objects surrounded by a double-lined frame correspond to objects in the *macro* representation scale. The objects framed with dotted lines are the objects within the *medium* scale. The data processing principle implemented in this case was to connect spatially several information; which when combined, relate to the hydrological properties (e.g. slope, drainage capacity) of the various relevant sectors of the city (e.g. activity zones, district). The *Socio-economic Activity Zone System*, the *Urban Infrastructure System* and the *Drainage System* represent the input data. The *Hydrological System* contains the output data, which has the synthetic properties necessary to identify the sectors where alternative drainage techniques can be used.

4.3 Results

The property analyzed here was the hydrological response time of an area delimited by an urban space composed of urban surfaces (characterized by topography), active surfaces (impervious surfaces for run-off water) and a drainage network. The goal of this analysis was not to quantify precisely this synthetic information, but rather to assess it roughly onto various sectors in the city’s test site. To this end, we extracted, classified and combined the data of the various layers involved, then we aggregated and represented them on the various sectors of the city. This allowed us to establish at the *macro* and *medium* scales:

- the map of urban surfaces classified in three intervals according to the extent of the combined slope (resulting from the average slope of the drainage network and the active surfaces considered) (figure 3 frames *a* and *d*),
- the map of urban surfaces classified in three intervals according to the drainage capacity (the ratio between the length of the drainage network and the active surfaces considered) (figure 3 frames *b* and *e*).

By means of a special request that selects the surfaces which have both a strong combined slope and a strong drainage capacity, we determined the areas likely to have the shortest hydrological response time. We could then identify:

- two activity zones (figure 3 frame *c*) where it would be appropriate to encourage the development of alternative drainage techniques and so to reduce the maximum flow downstream to the main combined network. For example, one of these alternative drainage techniques could be the temporary storage of storm water,
- two priority districts (figure 3 frame *f*) where actions such as equipping roads with water reservoir for the temporary storage of storm water could be carried out.

This geographical refinement makes it possible to define a water management policy in short / long term by sector, and to extract information (soil layers, ground water level, existing outlets, infrastructures and networks) that can be used later to choose and design relevant solutions.

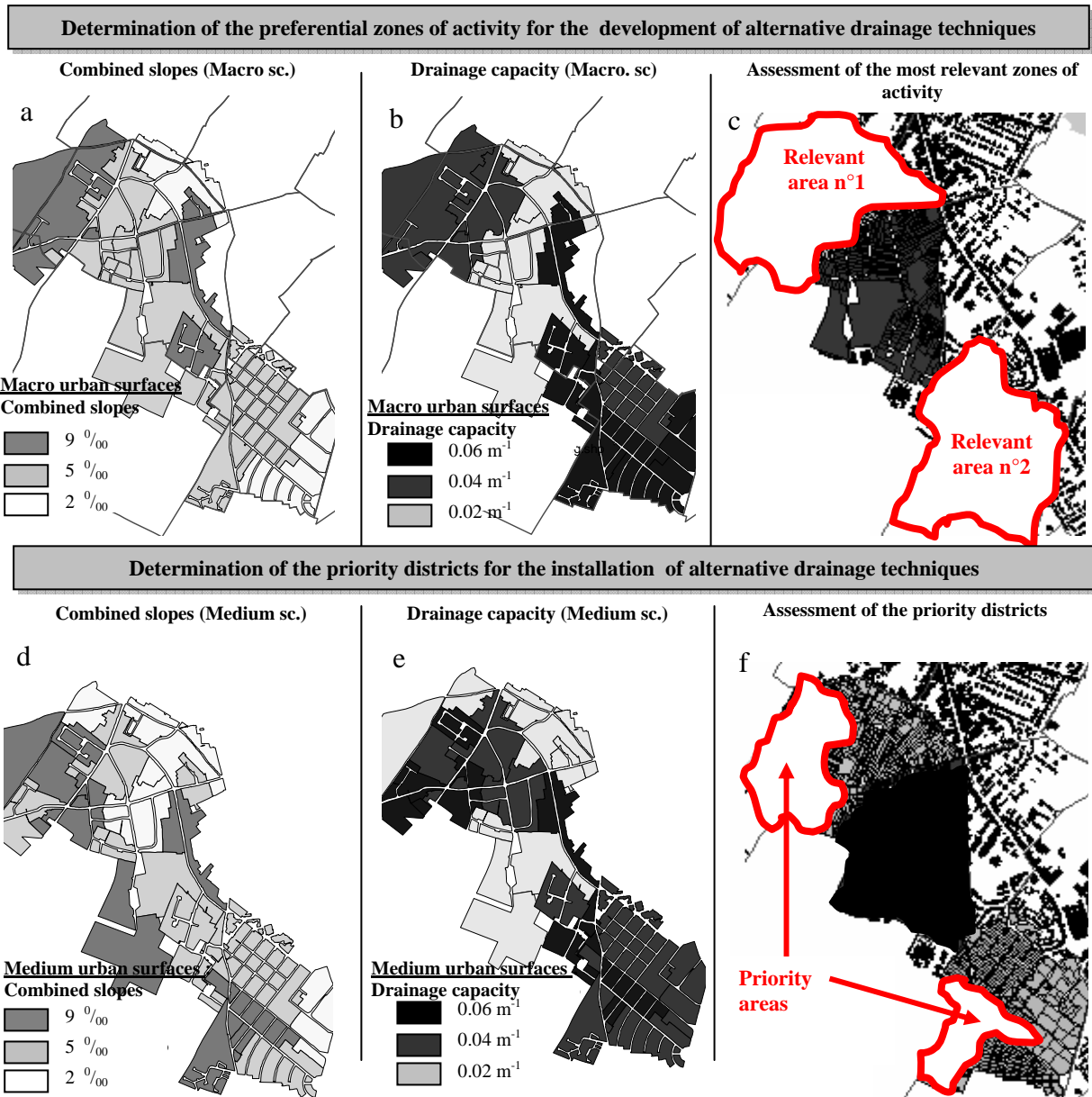


figure 3. Determination of the preferential sectors for the development of alternative drainage techniques

5. CONCLUSION AND FUTURE DEVELOPMENTS

In this article, we presented an approach and a systemic drainage model to contribute to the sustainable management of drainage infrastructures. The fact of considering several systems representative of their environment makes it possible to distinguish more explicitly the various aspects of drainage management. The model allows a multi scale analysis of the drainage project : from the *micro* scale of the drainage pipe itself, up to the *macro* scale of the drainage network.

The first applications tested, with rather simple data processing (database requests), showed the feasibility and the interest of the model, as well as the simplicity of its implementation on a GIS platform. The application presented here has brought to the CCNE a better understanding of its drainage system and its environment, in particular concerning the sectors relevant for the development of alternative drainage techniques. The promising results obtained from this initial research should encourage policies for better data capitalization and management in medium-sized intercommunalities.

The proposed model and the tools tested in our application (GIS, DBMS) can support the development of such policies. The potential applications of this open model are numerous, for example; the management of inherited (i.e. existing) drainage networks and roadway systems as well as the development of drainage systems for new activity zones.

ACKNOWLEDGMENTS

We wish to acknowledge the CCNE and the Regional Council of “Nord pas de Calais” for their financial support. We would also like to thank Bryony WHITE for her translation support.

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