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Air Quality Management - A Review

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Abstract: One of the main challenges in today's society is to have timely and appropriate access to relevant and good quality environmental data. The aim is to enable actions whenever environmental requirements and limits are violated. The objective of this review is to develop a planning tool to help local authorities and interested users to evaluate the present air quality or to asses on the environmental impact of future scenarios, localization of new industries, changing urbanization conditions or transportation systems and increasing vehicle circulation. Particularly this study aimed to establish the air quality in the industrial area of the city and its influence in the urban area. There is an increasing need for integrated solutions, which include monitoring data and planning tools into one system. Project phase includes monitoring, second modelling, third implementation of GIS and last phase includes development of system for decision support. Further, a GIS based decision making is expected to make air quality management system more efficacious and may be adopted as an efficient and cost effective approach for continuous improvement of air quality status.

Key words: Gaussian · Armed · AQMS · Health Risk · Implementation

INTRODUCTION

Air pollution is defined as any atmospheric condition in which certain substances present in such concentrations and duration that they may produce harmful effects on man and his environment [1]. Common air pollutants include carbon monoxide, nitrogen oxide, sulphur dioxide, total suspend particular matter (TSM) which includes dust, smoke, pollen and other solid particles. The air pollution reaches to a level which can significantly influence human's health. For each city clean air is one of the most valuable sources. Air quality management system (AQMS) can be defined as a regulation of the amount, location and time of pollutant emissions to achieve some clearly defined set of ambient air quality standards or goals. For an efficient AQMS, there is a need to define a decision support system [2].

Air pollutants are added in the atmosphere from variety of sources that change the composition of atmosphere and affect the biotic environment. The concentration of air pollutants depend not only on the quantities that are emitted from air pollution sources but also on the ability of the atmosphere to either absorb or disperse these emissions. The air pollution concentration vary spatially and temporarily causing the air pollution pattern to change with different locations and time due to changes in meteorological and topographical condition. The sources of air pollutants include vehicles, industries and natural sources. Because of the presence of high amount of air pollutants in the ambient air, the health of the population and property is getting adversely affected. In order to arrest the deterioration in air quality, Govt. of India has enacted Air (Prevention and Control of Pollution) Act in 1981. The responsibility has been further emphasized under Environment (Protection) Act, 1986. It is necessary to assess the present and anticipated air pollution through continuous air quality survey/monitoring programs.

Effective climate and air quality management require knowledge of the sources of air pollutants in a region, the ability to understand and project the emissions from those sources and the ability to handle the regulatory processes associated with controlling emissions from those sources. This is an ongoing challenge for regions with ample

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resources; the challenge is even greater for developing countries with limited information and disparate local planning programs.

Air quality management is a complex issue. Unlike many other government functions, like taxation or infrastructure development, there is no historic government analog available to implement the air quality improvement programs and management of air quality requires interaction between many different government sectors (such as transportation, energy, water resources, urban planning). Furthermore, the science of air pollution formation is complex and sometimes has counterintuitive explanations and new confounding issues seem to crop up regularly.

Air pollution control actions go back at least as far as the thirteen century but the major effort has taken place since 1945 [3], where the awareness of air pollution gradually increased among people all over the world. Before 1945, air pollution controls for industrial activities were directed at controlling large-factory emissions of pollutants that had led to conflict with neighbours of the factories, which do not involve any governmental actions [4]. Air pollution is a global problem, since the pollutants become dispersed throughout the entire atmosphere. Pollutants are introducing to the atmosphere are subject to numerous impacts that implies the contact of both air components and other pollutants. According to [5], reactions between pollutants and air are more frequently taking place than between pollutants themselves.

Air pollution is impacting the lives of millions of people by causing damage to humans and the environment that may prove to be irreversible. Conditions that are exacerbated by air pollution include asthma, cardiovascular disease, pneumonia and others [6]. Much of the air pollution affecting humans and the environment is the result of human activity. These activities have increased due to population growth, increased energy consumption and augmented industrial production. Evidence exists which indicates that humans will be negatively impacted if environmental degradation continues [7]. From a health perspective, there are moral obligations to communicate this impact to the public [6].

Unwanted constituents in air can have a detrimental effect on human health, on the health of other creatures, value of properties and the quality of life. There are many dramatic evidence shows that ambient of air pollution can seriously endanger public health like in Meuse Valley, Belgium in 1930, Donora, Pennsylvania in 1948 and London, England in 1952. The causal role of pollutants ambient in producing adverse health effects normally experienced in industrialized urban environments, where many disease can occur such as chronic respiratory disease and upper respiratory infections such as bronchitis and pneumonia, cardiovascular disease, asthma and irritation of eyes, nose and throat [8].

In terms of health effects, particulate air pollution is associated with complaints of the respiratory system (WHO, 2000). Particle size is important for health because it controls where in the respiratory system a given particle is deposited. Fine particles are thought to be more damaging to human health than coarse particles, as larger particles are less respirable, in that they do not penetrate deep into the lungs, compared to smaller particles [9]. Larger particles are deposited into the extrathoracic part of the respiratory tract while smaller particles are deposited into the smaller airways leading to the respiratory bronchioles (WHO, 2000).

On man, air pollution is now associated with respiratory and eye diseases such as asthma, lung cancer and conjunctivitis, especially in the young and elderly [10]. On the environment, air pollution is a major contributor to effects such as acid rain, which has been responsible for much damage to soil, fish resources and vegetation, often very far away from the source of the pollutant (Acid Rain 2001). Air pollution is also responsible for the effect of smog, which is a reduction in visibility due to scattering of light by airborne particles. It may also cause offensive odours in addition to soiling buildings and monuments [40]. However, by far, the most serious long-term environmental effect of air pollution is global warming, which, it is now recognized, may soon threaten the very existence of human life, especially in the coastal and highland regions. Concern about global warming led to the famous Kyoto Protocol of 1997, through which over 100 countries undertook to reduce their emissions of certain pollutant gases significantly [11, 12].

High air pollution load in urban cities has been a major contributing factor towards degrading the ambient air quality day by day [13]. Urban air pollution remains as a serious environmental problem, whose solutions must have priority, but also an adequate approach. Air quality assessment faces new and continuing challenges, because of the growth of urban conglomerates, population growth and rapid urbanization. Monitoring is essential to assessing the effectiveness of air pollution control actions. The goal of an Air Quality Information System (AQIS) is, through monitoring, to keep authorities, major polluters and the public informed on the short-and long-term changes in air quality, thereby helping to raise awareness.

Proper management of the problem is considered to be quite complex due to lack of accurate, up to date and organized geospatial data and analysis as well as lack of an integrated system for acquisition, storage, manipulation, retrieval, analysis, presentation and exchange of environmental data.

Modelling provides the ability to assess the current and future air quality in order to enable informed policy decisions to be made. Thus, air quality models play an important role in providing information for better and more efficient air quality management planning. An effective air quality management system must be able to provide the authorities with information on the current and likely future trends, throughout the area enabling them to make necessary assessments regarding the extent and type of the air pollution control management strategies to be implemented. Air quality management includes monitoring and analysis of pollutant concentration, spatial distribution of pollutant concentration, assessment of number of environmental factors affected by air pollutants, health risk map. Application and analysis of GIS for assessment of air quality is very useful for mapping and examine the Air pollutant data.

Air pollution models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. Air pollution measurements give information about ambient concentrations and deposition at specific locations and times, without giving clear guidance on the identification of the causes of the air quality problem. This makes air pollution models indispensable in regulatory, research and forensic applications.

An atmospheric dispersion modelling is a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation in the atmosphere. The model estimates downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere. The model calculates the pollutant concentration using information of the given meteorological, contaminant emission rate and characteristics of the emission source together with the local topography features. The ISCT3 is commonly used air dispersion software among researchers [14, 15] and it is recommended by the United States Environmental Agency to perform atmospheric dispersion modelling [16]. The ISCT3 is incorporated with the steady state Gaussian Plume Model and capable of evaluating the pollutant concentration emitted by point sources.

The air quality modelling is an important tool to predict transport, diffusion, dispersion and deposition of atmospheric pollutants. Many micros meteorological stack related and ambient related parameters were used for predicting the dispersion of air pollutants. The hazardous accumulation of air pollutants in one location due to poor atmospheric stability conditions such as thermal inversion, extremely stable conditions becomes a frequent phenomenon for predicting the impact on the gas pollutants on the flora and fauna of the surrounding environment.

Air pollution models can be categorised into 3 generic classes: deterministic approach, statistical models and physical models. Deterministic models basically deals with different types of numerical approximations (for example finite difference and finite techniques) in the solution of the partial equations representing the relevant physical process of atmospheric dispersion. For this process an emission inventory has to be available and other independent, mostly meteorological variables have to be known. The deterministic model is most suitable for long-term planning decisions.

In contrast to the deterministic model, the statistical one calculates ambient air concentrations using an empirical established statistical relationship between meteorological and other parameters on the other hand. Only semi quantitative conclusions can be drawn on some particular air quality issues. The statistical model is very useful for short-term forecast of concentrations. The advantage of such models is their small computational efforts that simulate measured concentration at one point or concentration field. No emission inventory is needed. The disadvantages besides that concentration measurement are needed. They can also be used to take into account background concentration in a deterministic model. Air dispersion models are computer tools that use mathematical equations to simulate how air pollutants disperse in the atmosphere. Air dispersion models are used to estimate or to predict the downwind concentration of chemical air pollutants from sources such as industrial plants, vehicular traffic, chemical storage facilities and accidental chemical spills.

Dispersion numerical models in the atmosphere are frequently employed to simulate continental and regional scale air pollution transport. Generally, two approaches are used to numerically reproduce air pollution turbulent diffusion: Eulerian and Lagrangian representations. In a Lagrangian analysis one follows a fluid particle as it is transported by the atmospheric turbulence action. On the other hand, in an Eulerian framework the different properties of a fluid flow are determined at a particular location in space for a given time.

Air pollution dispersion models are largely applied to describe the distribution of pollutants, in order to identify the contribution of different emitting sources and to forecast their impact on air quality. The models available are many, with different degrees of complexity and different performances; the simulation of pollutant dispersion by different models may produce not comparable results in some typical atmospheric conditions, such as wind calm, during which the dispersion processes are mainly driven by turbulence. Wind calms and high pressure conditions enhance pollutant accumulation in the atmosphere, leading to deterioration in air quality.

In order to predict the air pollutant, researchers have applied specific tools for specific pollutant emission sources. One of the common tools that being widely used throughout the world is the air dispersion modelling software consist of various models that fit into the research requirement [17]. It is also noted that limited of the predictions using different software models could be specifically recognized as the optimum result due to several factors. One of those is due to combination of very complex meteorological parameters such as the application of various techniques to estimate surface mixed layer depth above the ground. The various estimation of mixing height techniques has its own advantages that do not guarantee one is above to the other [18].

Mathematical models are used in all aspects of air quality planning where prediction is a major component, from episode forecasting to long term planning. In general, Gaussian and Numerical models are widely used for the simulation of urban air quality. The Gaussian models calculate the pollutant concentrations from emission inventory and meteorological variables according to the solutions of various equations that represent the relevant physical processes [19]. In other words, differential equation is developed by relating the rate of change of pollutant concentration to average wind and turbulent diffusion which, in turn, is derived from mass conservation principle [20]. Air dispersion models are used to estimate the downwind concentration of pollutants emitted by various pollution sources such as industrial facilities and regional public traffic. Dispersion models play an important role in the industrial and regulatory communities. Numerical simulations were carried out employing a Gaussian plume point source model (Goyal *et al*., 2003). SPM is considered to be the main pollutant emitted by the power station.

Air dispersion modelling has evolved greatly since the initial model development in the early twentieth century. At that time, air emissions from industrial and mobile sources were substantially unregulated and the dispersion process was not well understood [21]. By the 1950's, scientists were examining the dispersion process to predict atomic bomb fall out. In the 1960's and 1970's, two pioneering scientists, F. Pasquill and F.A. Gifford, developed basic dispersion curves that could be employed in modelling. Another scientist, G.A. Briggs developed equations to describe emissions plume behaviour known as "the Briggs Equations" which were widely used and helped advance scientific research in the area of air dispersion modelling. In the past, computer resources were limited and dispersion modelling calculations were often completed manually or by using relatively crude computer code [21].

The purpose of a dispersion model is to provide a means of calculating ambient ground-level concentrations of an emitted substance given information about the emissions and the nature of the atmosphere. The amount released can be determined from knowledge of the industrial process or actual measurements. However, predictive compliance with an ambient air quality objective is determined by the concentration of the substance at ground level. Air quality objectives refer to concentration in the ambient air, not in the emission source. In order to assess whether an emission meets the ambient air objective it is necessary to determine the ground-level concentrations that may arise at various distances from the source. This is the function of a dispersion model.

There are several approaches to model air-pollution dispersion: Gauss model (plume, puff) [22]. Regression models, box models, multiple cell models and other new approaches, e.g. [23, 24]. Used a Gaussian dispersion equation to predict dust concentrations from the stockpiles of an operating surface mine in Portugal. The equation is as follows:

$$C(x,y,z) = \frac{Q}{2\Pi\sigma_y\sigma_z u}\exp\left[\frac{-y^2}{2\sigma_y{}^2}\right]\left\{\exp\left[\frac{-(Z-H)^2}{2\sigma_Z{}^2}\right]+\exp\left[\frac{-(Z+H)^2}{2\sigma_Z{}^2}\right]\right\}$$

Where, c = pollutant concentration at location receptor Q = emission rate σ_y, σ_z = horizontal and vertical standard deviation respectively $\bar{u}$ = average wind speed, H= effective emission height. This equation was used to create risk maps of air quality for locations surrounding the mine site.

Although new types of dispersion models are now beginning to enter the regulatory arena, such as CALPUFF or TAPM (US EPA, CISRO), the Gaussian-plume models are still commonly used in assessing the impacts of existing and proposed sources of air pollution on local and urban air quality, particularly for regulatory applications. The steady-state Gaussian-plume models are based on the mathematical approximation of plume behavior and are the easiest models to use. They incorporate a simplistic description of the dispersion process and some fundamental assumptions are made that may not accurately reflect reality. However, the assumptions, errors and uncertainties of these models are generally well understood. So, even with these limitations, this type of model can provide reasonable results when used appropriately. The primary justification for the use of Gaussian diffusion models in regulatory applications comes from their evaluation and validation against experimental diffusion data.

Air dispersion modelling is an essential step in the air quality assessment process as it is the only way to evaluate the impact of future changes in air pollutant emission sources [25]. Dispersion modelling is computer tool that use mathematical equations to simulate how air pollutants disperse in the atmosphere. The model takes emissions from a source, estimates how high into the atmosphere they will go how widely they will spread and how far they will travel based on hourly meteorological data. The model then outputs the concentrations that will occur at the selected receptors.

An Eulerian dispersion model solves a conservation equation for gaseous or aerosol materials, which can be expressed formally very easy and which can be transformed into a very fast numerical code. On the other hand, Eulerian dispersion modeling is often rejected because of the appearance of artificial diffusion. Using the Lagrangian approach, trajectories of several thousands of particles have to be calculated in small consecutive time steps. Every particle carries a certain amount of gaseous or aerosol mass. The movement of the particle is determined by average wind velocity components and turbulence conditions. The latter is described mathematically by a Markov process. Concentration is calculated by counting particles or time-intervals of particles within the grid volumes. Artificial numerical diffusion does not occur by using this method, but, since statistic accuracy is important, usually a vast number of particle-trajectories have to be calculated, which may lead to very time-consuming simulations, especially, when low mesh width correspond with a large model domain [26].

Currently, the most commonly used dispersion models are steady-state Gaussian-plume models, providing an analytical solution to the dispersion equations. These are based on mathematical approximation of plume behaviour and are the easiest models to use. They incorporate a simplistic description of the dispersion process and can provide reasonable results when used appropriately [27].

Several studies have indicated that these Gaussian dispersion models do not perform well in urban environment particularly under traffic intersection and under street canyon conditions. However, integrated modelling approach involving new generation models within the GIS framework has been able to overcome most of the limitations, associated with Gaussian based dispersion models. Although, it is still not possible to completely describe mathematically, the complex atmospheric dispersion phenomena that is taking place in urban environment. The United States Environmental Protection Agency (EPA) recommends several different plume models for state implementation plans including CALINE 4 [28, 29 and 30]. CALINE 4 is aline source dispersion model specifically developed to model traffic generated pollution, while AERMOD, themo strecently developed plume model, is more flexi bleine mission sources and is widely considered state-of-the-art [31].

AERMOD is a steady-state Gaussian plume model which uses wind field derived from surface, upper-air and onsite meteorological observations combined with terrain elevations and land use. AERMOD is intended to handle a variety of pollutant source types, including surface and buoyant elevated sources, in a wide variety of settings such as rural and urban as well as flat and complex terrain. AERMOD is a Gaussian plume model designed for a continuous (straight-line plume) industrial source [30]. This model has undergone evaluation with field observations and ISCST3 [32]. Evaluated AERMOD with 17 datasets, 10 far-field and 7 near-field and found good performance for the far-field cases and mixed results for the near-field building downwash cases. Some of the 17 cases included near-surface non-buoyant sources and model performance ranged from reasonable to good. In a separate study, AERMOD evaluation results from two case studies with heavy gas, near surface, multiple point and area sources show a factor of 2 scatter and a 40% under-prediction [33]. AERMOD accounts for several PBL effects not accounted for by ISCST3 (Faulkner *et al*., 2008). Perry *et al*. (2005) compared several existing air dispersion models in terms of modeled and observed concentration distributions and concluded that with few exceptions the performance of AERMOD is superior to that of the other applied models.

Remote Sensing and Gis for Air Quality: Proper management of the problem is considered to be quite complex due to lack of accurate, up to date and organized geospatial data and analysis as well as lack of an integrated system for acquisition, storage, manipulation, retrieval, analysis, presentation and exchange of environmental data. Nowadays, geospatial information systems (GIS) as management and supporting systems, enable us to integrate and analyze a number of environmental data from different sources to model the overall impact of air pollutants on environment.

The recent development of spatial data management in the framework of geographic information systems (GISs) has created a new era of environmental modelling. More powerful computers have made running air quality models at global and local spatial scales possible. In order to understand the function of more complex models, the modelling system should consist of other subsystems (point and area sources of pollution, spatial description of terrain elevations, meteorological data and air quality monitoring networks).

A geospatial information system (GIS) is a computer-based information system which enables us to capture, model, manipulate, retrieve, analyze and present the geographically referenced data (Runoff, 1991). Geospatial applications for modelling of air pollution through importing, geo-referencing, spatial data editing, surface modelling, relief shading, pseudo color editing, creating and using region, extracting and merging vectors, supervised classification, polygon grid sampling, extracting grid cell properties and theme mapping has been studied by [34].

A Geographic Information System (GIS), a technology that can handle information on both location and its characteristics within a single system, is increasingly recognized as a powerful modeling tool in a variety of fields [35-37]. While GIS's visualization capability is widely used, the modeling capability of GIS is relatively underutilized [39-41]. With the increasing supply and usability of spatial data, GIS has a great potential to easily and accurately model the urban components and to systematize the modeling process.

A final level of integration in AQMS is between the information system and the human end user, or in more abstract terms, the decision making process that uses the management information system as an input. Despite different dispersion models and quite different user group and their specific requirements, this system needs a flexible client-server implementation for distributed and decentralized use of information resources [42]. To facilitate easy access to complex technical information and tools of analysis to the broad group in the environmental policy and decision making process, an understandable user interface is required.

The GIS based decision support system (DSS) provides an advanced modelling and analysis system for environmentalists so that they can reliably generate and simulate more information about environmental parameters [13]. One of key components in spatial DSS is the data warehousing and analysis. For air quality monitoring, numerous records of meteorology, pollution and other related data for last several years are needed to be analyzed which may be done efficiently by developing decision support system under GIS environment.

To provide decision making relevant information, integration of GIS with data bases, monitoring results from observation networks and spatially explicit dispersion modelling must be provided. The GIS platform, on which the system is operated and in which maps are developed and integrated, provides easy access to the data and gives a perfect and easily understandable data presentation (End regard). Modelling of the pollution dispersion with a GIS is a powerful way of making the modelled results user-friendly and easily understandable for local authorities as well as the public [42]. Therefore, the general idea of such integrated system is to improve the decision making process for policy makers by providing a professional tool to assist air quality planning.

Everything around us changes at different rates. Most of the phenomena change over time so spatio-temporal GIS have been developed [43]. Traditional GIS applications deal with sets of static objects, many spatial referenced objects change with time and more and more applications referred to location and time are considered; therefore the necessity of using spatio-temporal GIS is inevitable. A spatio-temporal GIS aims to process, manage and analyze spatio-temporal data [38].

In order to examine the spatial and temporal distributions of trace gas measures and their relation to urban components, Kawabata, 2003 created base maps that show trace gas measures on top of the layers of urban backgrounds such as orthophotos and roads. Second, measurements of land use, population density and roads are developed and combined into a grid cell matrix. Third, created Oracle tables that can adjust the cell values according to the directions and speed of wind. Finally, spatial regression analysis is performed to examine the effect of urban components on trace gas concentrations.

The [44] utilized a geographic information system (GIS) which integrates a vehicle emission model, pollutant dispersion model, backward trajectory model and related databases to estimate the emissions and spatial distribution of traffic pollutants in Taichung, Taiwan, ROC. The model not only can analyze the current pollution situations, but also can predict the emissions influenced by changes in specific traffic conditions or management policies. [45], has studied GIS techniques and remote sensing in evaluating wildfire impacts on air quality [46].

Remote sensing is the technique of deriving information about objects on the surface of the earth without physically coming into contact with them. This process involves making observations using sensors (cameras, scanners, radiometer, radar etc.) mounted on platforms (aircraft and satellites), which are at a considerable height from the earth surface and recording the observations on a suitable medium (images on photographic films and videotapes or digital data on magnetic tapes) [47]. The satellite based sensors provide valuable information useful in assessment, monitoring and management of air quality systems. Remote sensing technology in recent years has proved to be of great importance in acquiring data for effective resource and environmental management and hence could also be applied to environment monitoring and management.

GIS is used to process and interpret satellite imagery and to produce valuable tools for environmental dust analysis [48]. Increased resolution from improved satellite imagery, combined with GIS technological advancements, provides environmental managers with incredible geospatial research images. On-the-ground field crews, using mobile GIS technology, capture additional geographic data and perform inspections, dust inventories and site verification, all of which are uploaded to the geospatial database. Maps produced with GIS can alert scientists to notify people residing in areas where hazardous dust is approaching to take precautions [49]. Decision makers use environmental dust maps to implement dust control measures, such as vegetative covering, barrier methods, irrigation and street sweepers. Thus remote sensing and GIS technologies are widely used for today's management systems [50].

CONCLUSION

The air pollution problem originating from the various sources can be controlled by the development of air quality management system [51]. The seasonal air pollution surfaces are useful for wide range of purposes: for health risk assessment of the population within the study area, to assist in establishing and monitoring air quality standards and to evaluate transport policies [52]. For high accuracy it is necessary to study meteorological parameters like wind direction, wind speed, temperature, altitude which affect pollutant dispersion. It is possible to improve the spatial predictions of air pollution levels by deriving an empirical regression model of the relation between pollutants and independent variables which is the aim of the next step of the research [53].

Since air pollution produced by industries has become a major concern to urban planners, developers and health officials, it is necessary to check more frequently on the pollutant emission quantities and their spatial distributions and also to evaluate the variation of these situations caused by changes in certain management policies. Hence, there are growing needs for tools that can provide an easy access to obtain up-to-date mobile source emissions information. The integrated model which combined emission estimator, dispersion model and databases in a GIS framework should be a suitable tool to satisfy the needs mentioned above.

Despite the complexity of the spatial data management, analysis and visualization, modelling of air pollution has to be solved independently in the framework of standalone computer systems (mathematical modelling or physical scaled models). The GIS therefore serve as the data stores, which can manage all the data together with model outputs to carry out risk assessment analysis and map compositions.

Although extensive research has been done to develop strategies to reduce air pollutants, the magnitudes and spatial-temporal dimensions of gaseous and aerosol pollutants and their relation to urban activities are not well known. This limited knowledge is partly due to the difficulty in examining the large and varied contents of the urban emissions and partly due to the difficulty in measuring urban components [54].

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