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On-line Control of the Natural and Anthropogenic Safety in Krasnoyarsk Region

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Abstract**—**This paper presents an approach of on-line control of the state of technosphere and environment objects based on the integration of Data Warehouse, OLAP and Expert systems technologies. It looks at the structure and content of data warehouse that provides consolidation and storage of monitoring data. There is a description of OLAP-models that provide a multidimensional analysis of monitoring data and dynamic analysis of principal parameters of controlled objects. The authors suggest some criteria of emergency risk assessment using expert knowledge about danger levels. It is demonstrated now some of the proposed solutions could be adopted in territorial decision making support systems. Operational control allows authorities to detect threat, prevent natural and anthropogenic emergencies and ensure a comprehensive safety of territory.

Keywords**—**Decision making support systems, Emergency risk assessment, Natural and anthropogenic safety, On-line control, Territory.

I. Introduction

THE worldwide trend of ever increasing quantities and scale of natural calamities, anthropogenic disasters and accidents requires new solutions to ensure the safety of population and territories and introduce new methods and technologies to predict and prevent emergencies. Early prevention of natural and anthropogenic emergencies is a major factor for effective territory safety management. To decrease the risk of emergency one has to provide for comprehensive monitoring of current processes, real-time control of emergency sources and adequate assessment of threats [1]-[4]. At present, a lot of safety tools for operational observation of technosphere and environment objects parameters are being actively introduced, a huge amount of data is collected and processed in industrial automated systems [5]-[9]. Rising of efficiency in applying informational resources and operability of solving analytical tasks require the development of techniques of on-line control of the natural and anthropogenic safety that provide modelling of present conditions and assessment of emergency risk.

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In the paper, it is suggested to apply the approach of on-line control of the state of technosphere and environment objects in Krasnoyarsk region based on the integration of Data Warehouse, OLAP and Expert systems technologies. The data warehouse provides the data storage and its consolidation from heterogeneous sources. The OLAP technique allows to model the state and carries out the multidimensional data analysis for different monitored fields. The expert system technology makes it possible to assess the degree of danger and emergency risks using expert knowledge. The practical importance of this work lies in the adoption of the proposed solutions in the territorial automated systems.

The outline of this paper is as follows: Section II describes the structure, tasks and problems of monitoring emergencies in the Krasnoyarsk region. Section III presents the structure and content of data warehouse. Section IV considers a set of OLAP-models for modelling of the state of controlled objects. Section V describes the criteria of emergency risk estimation using expert knowledge. Section VI demonstrates the adoption of proposed solutions to ensure a comprehensive safety in Krasnoyarsk region. Section VII comprises the basic conclusions and issues for future research.

II. Comprehensive Control of the Territory Safety

Krasnoyarsk region is the second largest federal subject of Russia and the third largest subnational governing body by area in the world. Krasnoyarsk region lies in the middle of Siberia and occupies an area of 2,339,700 square kilometers, which is 13% of the country's total territory. This territory is characterised by heightened level of natural and anthropogenic emergencies which is determined by social-economic aspects, large resource potential, geographical location and climatic conditions. According to an annual report of the Ministry of emergency, in the territory there are many accident prone technosphere objects: 2 radiation-related objects; 45 chemically-dangerous objects; 89 fire-hazardous and dangerously explosive objects; almost 500 hydraulic facilities with more than 30-years in operation; 9 critically important objects, a lot of survival objects including boiler plants, power plants, pipelines and networks. Moreover, the territory is located in seven climatic zones. A number of large-scale natural emergencies are recorded each year, namely: flood, forest fire, gale-strength wind, anomalously low temperature and snow avalanche [10].

In order to improve the territory safety, local authorities take some emergency prevention and mitigation actions. A lot of automated monitoring systems based on advanced information and communication technologies are being

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actively introduced within the region. The main core of the regional emergency management is the Center of emergency monitoring and prediction of Krasnoyarsk region (CMP) [11]. Forecasting and estimation of emergency risk and consequences are major functional tasks of CMP. One of basic tasks that provide early emergency preventing is an operational control of the state of technosphere and environment objects. CMP collects the actual data from territorial monitoring systems and automatic control systems (sensors) directly. Regional monitoring system uses the meteostations, automatic dosimeters and gas analyzers and snow level meters. The applied modern devices provide the high measurement accuracy for a lot of parameters and substances, the high reliability in inclement climatic conditions and guaranteed ten-year lifetime. Based on monitoring data CPM forms operational and strategical recommendations aimed at emergency prevention. CPM presents the results of data analysis, emergency assessments and predictions to regional and federal authorities and informs population about current situation. Fig. 1 illustrates the organizational structure of monitoring system in Krasnoyarsk region.

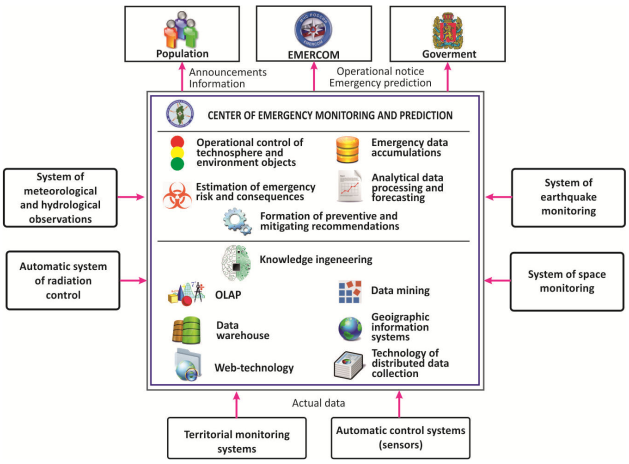


Fig. 1 Organizational structure of monitoring system in Krasnoyarsk region

Comprehensive data processing requires to be developed a united informational resource on the basis of consolidation and centralized storage of monitoring data. Providing on-line control of the state of technosphere and environment objects requires new techniques of analytical modelling of current conditions and assessment of danger degree based on the application of multidimensional data analysis and expert knowledge.

III. Data Warehouse of Monitoring Data

Data warehousing is an approach to integrate information from multiple, very large, distributed and heterogeneous operational databases and other sources. A data warehouse is a subject oriented, nonvolatile, integrated, time-variant collection of data that works in support of management's decisions [12]. The structure of data organization in a data warehouse defines the opportunity to apply such modern technologies as OLAP and Data Mining. To control the state of technosphere and environment objects there has been developed the special structure of centralized data warehouse which combines historical, operational and reference data [13]. Depending on the specific features of domain, the structure of data warehouse includes three basic layers:

1) Layer of stationary storage that consists of facts tables and dimensions tables.
2) Layer of analytical objects that contain the analytical models which are used for on-line analytical processing, the aggregates tables and reports.
3) Layer of pre-loading processing that provides loading and preliminary data processing from heterogeneous operational databases and contains data sources, import and export procedures and temporary tables.

The fragment of stationary storage content for different monitored fields is shown in Table I. Thus, the centralized data warehouse combines monitoring data from different sources and makes up a united informational resource for further data processing: analytical modelling and assessment [9].

TABLE I
The Fragment of Stationary Storage Content

Monitoring fields	Facts tables	Dimension tables
Controlled events	Emergencies Forest fires	Territories, Event types, Event scale, Event causes
Meteorological situation	Meteorological data, Weather forecast	Territories, Meteostations, Sensors
Hydrological situation	Water level in rivers, Water level in hydro-power plants, Ice conditions	Territories, Water bodies, Hydroposts, Hydropower plants, Freezing-over types
Flood situation	Flood areas, Condition of hydraulic facilities	Territories, Hydraulic facilities types, Hydraulic facilities states, Water bodies
Snow avalanche situation	Snow level	Territories, Sensors
Seismological situation	Seismic events	Territories, Seismic stations, Seismic event types
Seismological situation	Seismic events	Territories, Seismic stations, Seismic event types
Radiation and radiochemical situation	Exposure dose of gamma-ray Chemical substances	Territories, Sensors
Municipal facilities	Accidents in municipal systems, Preparation for heating season Condition of objects	Territories, Municipal objects, Municipal objects types, Municipal accidents types, Fuel types, Financing sources, Municipal services
State of superstructure	Level of snow load, Deformation range	Territories, Buildings, Sensors

IV. Analytical Modeling the State of Techno sphere and Environment Objects

Analytical modelling the state of technosphere and environment objects is based on OLAP (On-line Analytical Processing) technology that provides an efficient means to analyze and present data as an easy-to-understand and an easy-to-use data model in form of multidimensional cubes [14]. The set of specific OLAP-models has been developed for on-line control of territory safety [15]. Description of OLAP-models for each of the monitored fields is represented in Table II.

TABLE II
OLAP-MODELS FOR MODELLING STATE

Monitoring fields	OLAP-model characteristic
Controlled events	*OLAP-model:* Emergencies *Facts:* Fatalities, Victims, Material damage *Dimensions:* Year, Event date, Event liquidation date, Place, Event type, Event scale and Event cause
	OLAP-model: Forest fires *Facts:* Fatalities, Victims, Material damage *Dimensions:* Year, Event date, Event liquidation date, Place, Event type, Event scale and Event cause, Fire-prevention groups
Meteorological situation	*OLAP-model:* Temperature *Facts:* Temperature *Dimensions:* Year, Place, Date, Meteostation
	OLAP-model: Speed and direction of wind *Facts:* Speed of wind and Direction of wind *Dimensions:* Year, Place, Date, Meteostation
	OLAP-model: Weather forecast *Facts:* Tendency *Dimensions:* Date, Territory
	OLAP-model: Meteorological data from sensors *Facts:* Temperature, Speed and direction of wind, Air moisture, Atmospheric pressure *Dimensions:* Year, Place, Date, Sensor
Hydrological situation	*OLAP-model:* Water level of the rivers *Facts:* Water level of the rivers, Crucial water level of the rivers, Exceeding of crucial water level *Dimensions:* Year, Date, Month and day, Hydroposts, River
	OLAP-model: Water discharge of the hydropower plants *Facts:* Minimal acceptable level of discharge, Maximal acceptable level of discharge, Water discharge level *Dimensions:* Year, Date, Hydro power plant
	OLAP-model: Water level of hydro-power plants *Facts:* Water level of the hydro-power plants, Crucial water level of hydro-power plants, Exceeding of crucial water level. *Dimensions:* Year, Date, Month and day, Hydro power plant
	OLAP-model: Ice conditions *Facts:* Count of ice events, Ice event description *Dimensions:* Year, Date, Hydroposts, River, Freezing-over type
Flood situation	*OLAP-model:* Flood forecast *Facts:* Minimal expected water level, Maximal expected water level, Fact water level in the last year *Dimensions:* Year, Territory, Hydroposts, River, Date of expected flood, Date of fact flood in the last year
	OLAP-model: Hydraulic facilities condition *Facts:* Volume of hydraulic facility, Square of hydraulic facility *Dimensions:* Year, Place, Water body, Hydraulic facilities, Hydraulic facilities type, Hydraulic facilities state
Snow avalanche situation	*OLAP-model:* Snow level *Facts:* Snow level, Maximal acceptable snow level *Dimensions:* Date, Place, Sensor
Seismological situation	*OLAP-model:* Seismic events *Facts:* depth, magnitude, diameter of the transient cavity, epicenter coordinates *Dimensions:* Year, Date, Place, Seismic station, Sensor, Seismic event type
Radiation situation	*OLAP-model:* Expose dose of gamma-ray *Facts:* Exposure dose of gamma-ray *Dimensions:* Date, Place, Sensor
Municipal facilities	*OLAP-model:* Municipal accidences *Facts:* Adult victims, Children victims, Count of accidence, Accidence causes, Liquidation actions *Dimensions:* Date, Place, Sensor
	OLAP-model: Municipal accidences forecast *Facts:* Population, Probable victims, Probable accidence, Probable liquidation actions *Dimensions:* Year, Place, Report date, Municipal object
State of span	*OLAP-model:* Fuel reserve *Facts:* Requirement of fuel, Fact reserve of fuel, Readiness *Dimensions:* Year, Territory, Fuel types, Report date
	OLAP-model: Pressure of hot water supply *Facts:* Current pressure, Minimal acceptable pressure, Maximal acceptable pressure, Departure from minimum, Departure from maximum *Dimensions:* boiler plants, Date, Sensor
	OLAP-model: Temperature of hot water supply *Facts:* Current temperature, Minimal acceptable temperature, Maximal acceptable temperature, Departure from minimum, Departure from maximum *Dimensions:* boiler plants, Date, Sensor
	OLAP-model: Level of snow load *Facts:* Level of snow load, Maximal acceptable level of snow load *Dimensions:* Date, Place, Sensor
	OLAP-model: Deformation range of supporting girders *Facts:* Deformation range, Maximal acceptable deformation range *Dimensions:* Date, Place, Sensor

The developed OLAP-modes can be represented as statistical tables or cross-tables. A statistical table represents the analytical processing result as a relational table with data filtration and sorting functions. Moreover, it enables an analyst to process data with standard statistic functions such as: expectation, variance, quintiles, correlation and cluster analysis. A cross-table represents the multidimensional cube and provides the tool for intuitive manipulation of monitoring data. It allows an analyst to change the order of fields in vertical and horizontal header of the table, interchange facts and dimensions (table pivoting), choose the level of aggregation and detailing, "slice" and "dice" dataset. In addition, for geographical data the result of OLAP-model processing can be visualized as diagram or map [16]. All these facilities of the data visualization and manipulation provide the opportunity to change traditional point of view and discover new analytical relations between monitoring data for decision making.

V. Assessment of Danger Based on Analytical Indicators

The estimation of emergency risk are based on forming analytical indicators by comparing actual monitoring data with their critical values using expert knowledge. The analytical indicator is defined for each OLAP-model according to values of controlled parameters.

In order to form analytical indicator the knowledge presentation model has been developed which contains the collection of rules with the following general construction:

$$R : \text{IF} < condition > \text{THEN} < operation > \qquad (1)$$

where R – is a rule specification that identifies the name, the purpose and conditions of rule applying; "$\text{IF} < condition > \text{THEN} < operation >$" construction is a rule nucleus which is interpreted as a cause-effect relation; "$< condition >$" is an antecedent that describes the current situation and has a logical value: truth and lie. "$< operation >$" is a consequent that present one or more operations.

Specifying the elements of the general construction, the rules can be represented as a following detailed construction:

$$I{:}\ M{:}\ S{:}\ \text{IF} < (x_1 \sim a_{11}) \,\&\, (x_2 \sim a_{21}) \,\&\, \ldots \,\&\, (x_i \sim a_{ij}) \,\&\, (x_n \sim a_{nm}) > \text{THEN} < Q_k > \quad (2)$$

where I – is an identifier of unique rule name in knowledge base; M – is an identifier of effected zone – is a pointer to specific OLAP-model; S – is an identifier of rule priority that describes the privilege of rule for conflict resolution; x_i – is a value of controlled *i*-th parameter of OLAP-model; a_{ij} – is a critical value of *i*-th parameter for *j*-th danger level; "~" symbol is a comparative operation including >, <, =; Q_k – is an operation to designate analytical indicator value for *k*-th OLAP-model; $i = \overline{1,n}$, n – is a number of controlled parameters; $j = \overline{1,m}$, m – is a number of analytical indicator values; $k = \overline{1,K}$, k – is a number of OLAP-models.

The reasoning procedure based on rules is a sequential comparison of antecedent of rule with actual data and execution of relevant consequent.

In knowledge base there are three values of analytical indicator (danger levels):

- "Green" – the situation is normal – the value of controlled parameter does not exceed the critical value.
- "Yellow" – the situation requires attention – the value of controlled parameter is approaching to critical value, there is an emergency risk.
- "Red" – the situation is dangerous – the value of controlled parameter exceeds the critical value.

For each danger level according to geographical and climate specification of the territory the critical values of controlled parameters have been identified by experts. The criteria of emergency risk estimation are represented in Table III. Critical values, minimal and maximal acceptable values are identified monthly by expert committee based on the analysis of the current situation.

The comprehensive analytical indicator of monitoring field (situation) is identified by analytical indicators values of respective OLAP-models: the monitoring field has the worst danger level among danger levels of constituent OLAP-models. Thus, assessment of state of technosphere and environment objects based on analytical indicators using expert knowledge about danger levels provides the control of monitoring fields separately and territory safety as a whole.

TABLE III
CRITERIA OF EMERGENCY RISK ESTIMATION

Controlled parameter	Condition	Danger levels
Emergencies (E)	E count = 0	Green
	E count > 0, one or more days ago	Yellow
	E count > 0 today	Red
Temperature (T)	Else	Green
	30 ≤ T < 35 or -40 < T ≤ -35	Yellow
	T ≥ 35 or T ≤ -40	Red
Speed of wind (WS)	0 < WS < 15	Green
	15 ≤ WS < 25	Yellow
	WS ≥ 25	Red
Water level of the rivers (RL)	0 < RL< Critical value -10%	Green
	Critical -10% ≤ RL < Critical value	Yellow
	RL ≥ Critical value	Red
Water level of hydropower plants (HL)	Min+0.5<HL<Max-0.5	Green
	Min<HL≤Min+0.5 or Max+0.5≤HL<Max	Yellow
	HL≤Min or HL≥Max	Red
Ice conditions	Else	Green
	Freezing or Shearing of ice	Yellow
	Ice traffic jam	Red
Flood areas	Else	Green
	Buildings are in flood area	Yellow
	Industrial objects are in flood area	Red
Condition of hydraulic facilities	Else	Green
	Pre-crash state	Yellow
	State of emergency	Red
Snow level (SL)	Min< SL <Max	Green
	SL <Min or SL >Max	Red
Earthquake, magnitude (M)	M < 3	Green
	3 ≤ M < 5	Yellow
	M ≥ 5	Red
Expose dose of gamma-ray (ED)	ED < 20	Green
	20 ≤ ED < 40	Yellow
	ED ≥ 40	Red
Pressure of hot water supply (HWPr, atmosphere)	Min<HWPr<Max	Green
	HWPr<Min or HWPr>Max	Red
Temperature of hot water supply (HWT, °C)	Min<HWT<Max	Green
	HWT<Min or HWT>Max	Red
Level of snow load (LSL, sm)	Else	Green
	LSL ≥70	Yellow
Deformation range of supporting girders (D, mm)	D<0.4	Green
	0.4≤D<0.6	Yellow
	D≥0.6	Red

VI. IMPLEMENTATION OF ON-LINE CONTROL SOLUTIONS IN DECISION MAKING SYSTEMS

Proposed solutions are adopted in decision making supports systems to ensure a comprehensive safety in the Krasnoyarsk region [17]. The automated system of comprehensive monitoring "ESPLA-M" is a system of on-line control of natural and anthropogenic emergencies. Fig. 2 shows the visualization of hydrological situation (water level in the rivers) using a map with analytical indicators.

The automated system of emergency risk analysis "SAR" is a system of analysis and estimation of natural and anthropogenic risks. Figs. 3 and 4 show the "Water level of hydro power plants" OLAP-model as a cross-table and a diagram respectively.

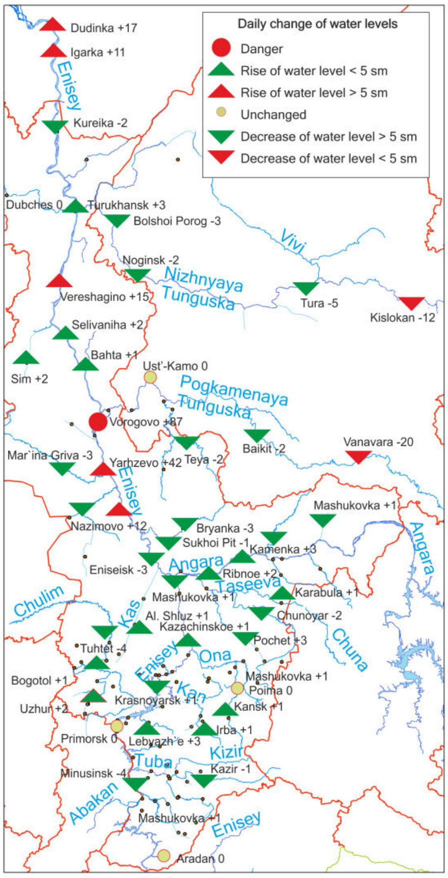
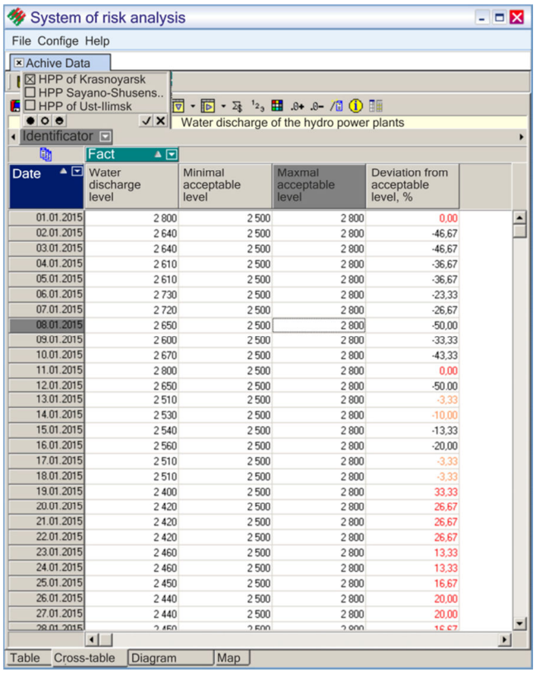


Fig. 2 ESPLA-M: Visualization of hydrological situation as a map with analytical indicators



Date	Water discharge level	Minimal acceptable level	Maxmal acceptable level	Deviation from acceptable level, %
01.01.2015	2 800	2 500	2 800	0,00
02.01.2015	2 640	2 500	2 800	-46,67
03.01.2015	2 640	2 500	2 800	-46,67
04.01.2015	2 610	2 500	2 800	-36,67
05.01.2015	2 610	2 500	2 800	-36,67
06.01.2015	2 730	2 500	2 800	-23,33
07.01.2015	2 720	2 500	2 800	-26,67
08.01.2015	2 650	2 500	2 800	-50,00
09.01.2015	2 600	2 500	2 800	-33,33
10.01.2015	2 670	2 500	2 800	-43,33
11.01.2015	2 800	2 500	2 800	0,00
12.01.2015	2 650	2 500	2 800	-50,00
13.01.2015	2 510	2 500	2 800	-3,33
14.01.2015	2 530	2 500	2 800	-10,00
15.01.2015	2 540	2 500	2 800	-13,33
16.01.2015	2 560	2 500	2 800	-20,00
17.01.2015	2 510	2 500	2 800	-3,33
18.01.2015	2 510	2 500	2 800	-3,33
19.01.2015	2 400	2 500	2 800	33,33
20.01.2015	2 420	2 500	2 800	26,67
21.01.2015	2 420	2 500	2 800	26,67
22.01.2015	2 420	2 500	2 800	26,67
23.01.2015	2 460	2 500	2 800	13,33
24.01.2015	2 460	2 500	2 800	13,33
25.01.2015	2 450	2 500	2 800	16,67
26.01.2015	2 440	2 500	2 800	20,00
27.01.2015	2 440	2 500	2 800	20,00

Fig. 3 SAR: Visualization of hydrological situation as a cross-table

These figures demonstrate the example of minimal and maximal acceptable levels of discharge, actual water discharge level and deviation from normal. The cross-table provides tool for intuitive manipulation of constructed cube and allows the user to analyze data in such dimensions as date and Hydropower plant. Analysis enables the analyst to investigate the structure and values of risks, to plan the preventative actions and predict the existing and future dangers for population and territory.

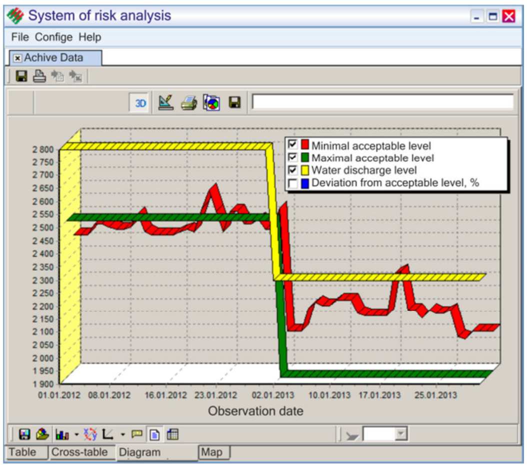


Fig. 4 SAR: Visualization of hydrological situation as a diagram

Web-application (http://www.cmp.krasn.ru) is an informational resource to display monitoring information and predicted data in region. You can see the risk indicators in general or detailed data for particular situation. Fig. 5 shows the page with visualisation of hydrological situation – is an overriding of water level in the rivers.

Fig. 5 Web-application: Operational control of hydrological situation

The proposed analytical tools of on-line control of the state of technosphere and environment objects are applied successfully in Ministry of emergency of Krasnoyarsk region for decision making support in territory safety.

VII. Conclusion

Integration of Data Warehouse, OLAP and Expert systems technologies provide a development of effective tools for on-line control of the natural and anthropogenic safety of the territory. The data warehouse technology provides the consolidation and centralizes storage of monitoring data about state of technosphere and environment objects by forming the united informational resource. On-line analytical modelling tools based on OLAP-technology provide a multidimensional analysis of monitoring data and dynamic analysis of principal parameters. Assessment technique of controlled objects based on analytical indicators using expert knowledge about danger levels provides emergency risk estimation for specific place or region as a whole. On-line control allows authority to prevent emergency and ensure a comprehensive population and territory safety.

The future research will be connected with developing the method of estimation of the safety territory based on hierarchical system of facts and multilevel scale of danger. In addition, authors are going to develop the model of generation of control recommendations based on estimation results and expert knowledge of territory risk levels.

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