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Paper for panel 4: Remote Sensing and Early Warning

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Development of integrated environmental monitoring systems based on remote sensing data and field researches. Arhangelskaya region. Russia.

Preface. Solid mineral deposits exploitation is an important part of up-to-date industry. However, the mineral resource industry brings about irreversible environmental changes. Mechanical, geochemical, hydrogeological impacts and as well as their non-linear interference determine these changes. The integrated environmental monitoring (IEM) system is necessary to investigate natural environment changes.

Integrated environmental monitoring (IEM) system is a complex of tools, methods and devices designed to investigate and supervise a natural environment influence and natural components changes. Existing structure of nature relations and interactions should be covered in the most complete way. According to the Russian legislation an IEM system should be an obligatory part of any solid mineral deposit project.

Similar system development is especially urgent for solid mineral deposits. Mining and processing integration works (MPIW) usually exploit solid mineral deposit. Field mining may bring different consequences for the whole number of natural components. Besides, field mining maybe in a difficult of access regions and extremely north regions. Ecosystems in these regions are the most sensitive for the anthropogenic influence and haven’t high stability.

Development of an IEM system brings the number of problems and questions. Multiway of the local influences, their interference and changes are among the main IEM system problems.

Different response rates of the natural components to external influence and interference of natural components are the additional IEM system problem. However, environment influence of a solid mineral deposit is not instant, this influence increases gradually and enlarges it's sphere of impact. Besides, the natural protective actions of MPIW directed to disperse and slow down field influence (e.g. waste water clearing basins).

The purpose of this work is to develop principles for the IEM system, determine the IEM system structure. Following objectives are solved: determination of IEM structure, placing IEM points and stations for local environment, determination of observed characteristics set and observation frequency.

MPIW real time reaction on environmental changes provides by IEM system. Changing actions of operating procedures may be taken in time.

Real time estimation of intensity and type of MPIW environment impact is the main aim of the IEM system development. Following objectives are solved:

- Determining ways and types of control natural components and MPIW environment impact processes
- Locating of monitoring points, stations, profiles, lines, and routes
- Determination of sets of observed characteristic for points and stations of a certain type
- Frequency and seasonality determination of specific characteristics
- Developing principles of compatibility for different types of monitoring points, stations, and lines.

IEM structure development (aggregate approaches)

IEM structure factors

Main factors define the IEM system structure:

1. *Deposit type and operating process properties.* MPIW of any deposit should have it's own set of operating processes depending on mineral type and final production type.

2. *Nature conditions of the deposit area*

3. *Impact source differentiation* – different MPIW units can be sources and absorbents of different material and energy flows. For instance: a stripping dump accumulates material as well as stripping dump material spreads to neighbor ecosystems by wind and water.

4. *Large distances between different deposit objects.* The impact complex acts on natural environment within a local area, intensity of impact complex decreases with a distance from the unit. Also we can find an area where specific deposit object impact will be poor noticed, but an aggregate deposit impact will be rather intensive and complex.

5. Properties of MPIW units neighbored ecosystems.

6. New landforms change natural water and wind migrations.

The IEM system structure and spatial location of monitoring points should base on evaluation of:

- deposit operating processes
- primary impact processes of different deposit units
- natural environment reaction
- transformation and migration processes. These processes provide impact transfer on neighbor ecosystems (e.g. geochemical flows evaluation)

Deposit operating processes analyzing should be based on:

- deposit type
- mining method type
- enrichment process type
- final production type

Primary impact processes analyzing should be based on:

- impacted natural component
- impact type
- objects spatial arrangement (impact source)

Natural environment reaction analyzing should be based on:

- natural component type
- component change rate
- different natural component interaction

Transformation and migration processes analyzing should be based on:

- migration type
- ecosystems type on the flow way
- final ecosystem type
- exchange reaction on the flow way

IEM system development principles.

The IEM system is automatic system designed to control interaction between MPIW units and natural environment. The IEM system tasks are: industrial impact of environment condition monitoring; type and intensity of nature and industry interaction processes control; dangerous environmental processes information organization and spread for environmental protection making decisions.

The IEM system should meet following requirements for successful operating:

1. Environmental control on deposit objects and deposit influenced area as well as informational support of planned environment protection actions.
2. Total monitoring of natural components.
3. Monitoring of the total area influenced by MPIW.
4. Observing quality control.
5. Real time getting and processing of information.
6. Quantity minimization of maintains staff.
7. System adaptation during operating..

Following function should be carried out for the environmental situation control:

1. Regular observations.
2. Primary data processing, storing and archiving.
3. Providing data finding and sharing.
4. Deposit object conditions estimating and monitoring processes forecasting
5. Environmental and geological situation output documents organization as well as development trends;
6. User's information distribution
7. Providing interaction with other systems.

The IEM system is rationally based on following principles for providing system functioning and meeting requirements,:

- considering landscape differentiation
- considering of natural components interactions and reaction integrity
- considering primary impact processes
- considering geochemical migration flows
- combination of point-contacted filed researched method and areal remote sensing methods
- integration of analyze and processing data
- using indication characteristic
- adaptivity of structure and work order

Observed characteristic set and observation order are defined according to specific environmental impact type. In general observed characteristic set may be like following:

Air emissions monitoring	temperature, humidity, volume and velocity of exhaust gases, concentration of pollutants (CP)
Waste water monitoring	water discharge and CP
Ground and underground water monitoring	level (pressure) and chemical compound
Soil monitoring	soil crossover morphologic properties, CP in accumulating soil, hydrothermal characteristics
Vegetation cover monitoring	plant association general characteristics, plant association forest mensuration characteristics, forest vegetation physiological characteristics.
Surface water monitoring	water level, water discharge, suspended sediment discharge, muddiness, spring and autumn ice phenomenas, water chemical compound, sediments CP
Ground fauna monitoring	faunistical compound , population quantity indicator species morphological characteristics
Water fauna monitoring	quality and quantity compound of bottom animals and drift, sippe distribution; fish fauna species compounds, main biological parameters, systemic condition
Geological hazards monitoring	process intensity process spread area

The IEM system example:

The IEM system of one of deposits in north Russian taiga region may serve as an illustration.

There are main MPIW units of environmental impact:

- Open pit (depth up to 400 m),
- Waste pile (volume up to 350 million cubic meters),
- Tailings dam (square up to 10 sq. km.),
- River course channel (length 3 km),
- Main camp with dressing plant (square 4 sq. km).

The region environmental properties.

The deposit area is situated in near-tundra zone of the north taiga.

Upper part of the geological record is:

1. Middle carbon sediments, such as sandstones with siltstone streaks, rarely limestone and gravelite streaks, and such as limestone and dolomitic limestone.
2. Neogene to quaternary mellow sediments cover aged rocks with continues mantle. There are fluvioglacial, ice-borne, lacustrine, lacustrine-swamp and alluvial sediments. Granulometric composition of this sediment is sand, loam, shingle, clay sand and peat.

Region relief is swamped and forested hilly-ridged plain. General slope is southeast direction with height from 120 to 160 m.

Swamping is the common process on the deposit region, karst and erosion processes are more rare. Rather shallow carbonates contribute to karst process development on watersheds.

Podzol gley, swamp podzol and swamp soils prevail in this region. Alluvial soil may be in the flood plains area.

Forests of the first protected category dominate in the deposit region.

Lichen, red bilberry and blackberry forests have the most spread. These forests grow up on heightened drained relief sections. Middle moistened blackberry and haircap-moss forests are found very frequently. Redundant moistened grass-sphagnous and sphagnous forests are found too. These forest grow up on poor flowing flat relief drops and bogs margin.

Coniferous forests dominate (pine forest – 41%, fir wood – 41 %, larch forest – 9%), the rest are birch wood.

Deposit region ground fauna is common for north taiga. Fish fauna has more diverse. Salmon, salmon trout, hunchback salmon, white salmon, grayling, white-fish, pike, perch, burbot, ruff, ide, roach and river flatfish spawn and fatten in region rivers.

Main type of primary impacts are singled out by analysis:

Table 1. Main types of man-caused influences.

Environment	Process	Process property and results
atmosphere	Atmospheric emission of the mineral spray	Wind-borne migration is equal for the whole territory because of relatively plain landforms. Wind-borne migration intensity and direction are became formed by dominated winds (in winter north-east direction, in summer south-west). Bogs and swamps are the natural storage of chemical pollutant and mineral spray.
	Atmospheric emission of accompanying mineral spray chemical pollutants	
	Atmospheric emission of nitric oxides, carbon oxides, sulfur dioxides, soot, flourine hydride, welding aerosols, sulfuric acid and yellow lead as result of heavy equipment working and plant operating	
	Atmospheric moistness changing as result of bogs and tailing dam evaporation	
hydrosphere	Changing rivers and streams beds location	Deposit is situated in basin of two rather big rivers and great number more fine rivers and streams. These facts complicate investigation of water regime and chemical composition changes monitoring of surface water. Waste waters of open pit change their chemical composition as a consequence of migration throw bog peat and geochemical barriers.
	Changing rivers and streams discharges	
	Changing chemical composition of water	
	Changing bogs moistness and water regime as result of waste water impact	
	Changing bogs water chemical composition	
	Depression cone appearance as result of open pit creation	

lithosphere	Huge ground volume mechanical migration as result of open pit, waste pile and tailings dam creation.	Man-caused steep forestless slopes forming. Negative geological hazards initialization (mud-streams, landslides).
	Landform configuration changing as result of mechanical ground migration.	
soils	Mechanical soil cleaning in building zone	Region soils haven't any economical value
	Soils moistness reducing as result of depression cone increasing	Soils became more denudration, especially sandy podzols .
	Soil moistness increasing in waste water zone.	Soil bog type is changed (from bog to swamp).
	Chemical composition changing	Pollutants are accumulated on geochemical barriers.
vegetation and animal world	Mechanical vegetation cleaning in building zone	Deposit is situated in near-tundra forest zone. Region forests are the first protection group. There are commercial fish species in region rivers (salmon, salmon trout, hunchback salmon, white salmon, grayling)
	Vegetation indirect influence by moistness changing, surface water chemical composition changing, ground water level reducing	
	Commercial fishes spawning grounds reducing	
	Commercial fishes quantity reducing as result of surface water chemical composition changing.	
landscapes (ecosystems)	Natural ecosystems differentiation changing as result of man-caused impacts	Rather complex natural ecosystem differentiation is exposed by integrity zonal man-caused impact.

Energy and materials flows from natural ecosystems to industry objects are the development of geosphere man-caused influence. There are several main flow types: wind migration, surface and underground water migration.

Geochemical flows analysis should base on:

- flow type
- migration agent type
- continuous flow transformation in ecosystem passing
- geochemical barriers location
- different flows convergence points location
- areas of changing flow type location (e.g. surface water flow into ground water flow

Main flows type and characteristic was received during investigation. (table 2)

Table 2. Geochemical flow main types

Flow	Flow source	Man-caused flow change	Pollutants	Influenced ecosystems
Wind migration	Dominated winds	Without man-caused change	Mineral spray, heavy equipment and plant chemical pollutants	All of the ecosystems
Surface and ground water migration	Natural rivers	By-pass river channel development, water regime changing of streams	Pollutants, migrated and accumulated from basins	Water ecosystems, riverside ecosystems
	Waste water dropping	Ground water appearance on the surface	Chemical pollutant appearance from underground layers	Bogs, ecosytems near tailings dam

	Water chemical composition migration and transformation	Changed ground water	Water and accompanying chemical agents	Bogs ecosystems

IEM system structure

IEM system consists of three subsystems:

- Data-Measuring Network (DMN). It is a hardware and software complex designed for collection and primary processing of observed characteristics.
- Data-Management Subsystem (DMS). It is a hardware and software complex designed for collection, analyzing and distribution managing data.
- Data Transfer Subsystem (DST). It is a hardware and software complex designed for data transfer inside the IEM system and data exchange with other systems

The IEM system DMN, based on above principles, combine monitoring stations controlling different components:

- integral monitoring (ground water, soil, vegetation)
- surface water
- air emissions and pollutions
- waste waters

Besides, river sections are chosen for annual fish monitoring, key stations and routs are chosen for ground fauna monitoring. Integral monitoring profiles are organized. Integral monitoring profiles are necessary for ground water, soil and vegetation changes control by natural gradients.

High resolution space imaging provides monitoring of the whole area.

Points, profiles and routs location are selected after special field researches. Ecosystem, geochemical, soil, and vegetation maps are developed during these researches, as well as using DEM and remote sensing data.

Special GIS operate with system management, data analyzing and environmental reports.

Figures 1 and 2 show DMN elements placing near waste pile, open pit, tailing dump and dressing plant. The main migration ways are controlled with monitoring points groups. Each group consists of integral monitoring points as well as soil, ground, and surface water monitoring points.

Fig 1. A DMN elements placing scheme (tailing dam).

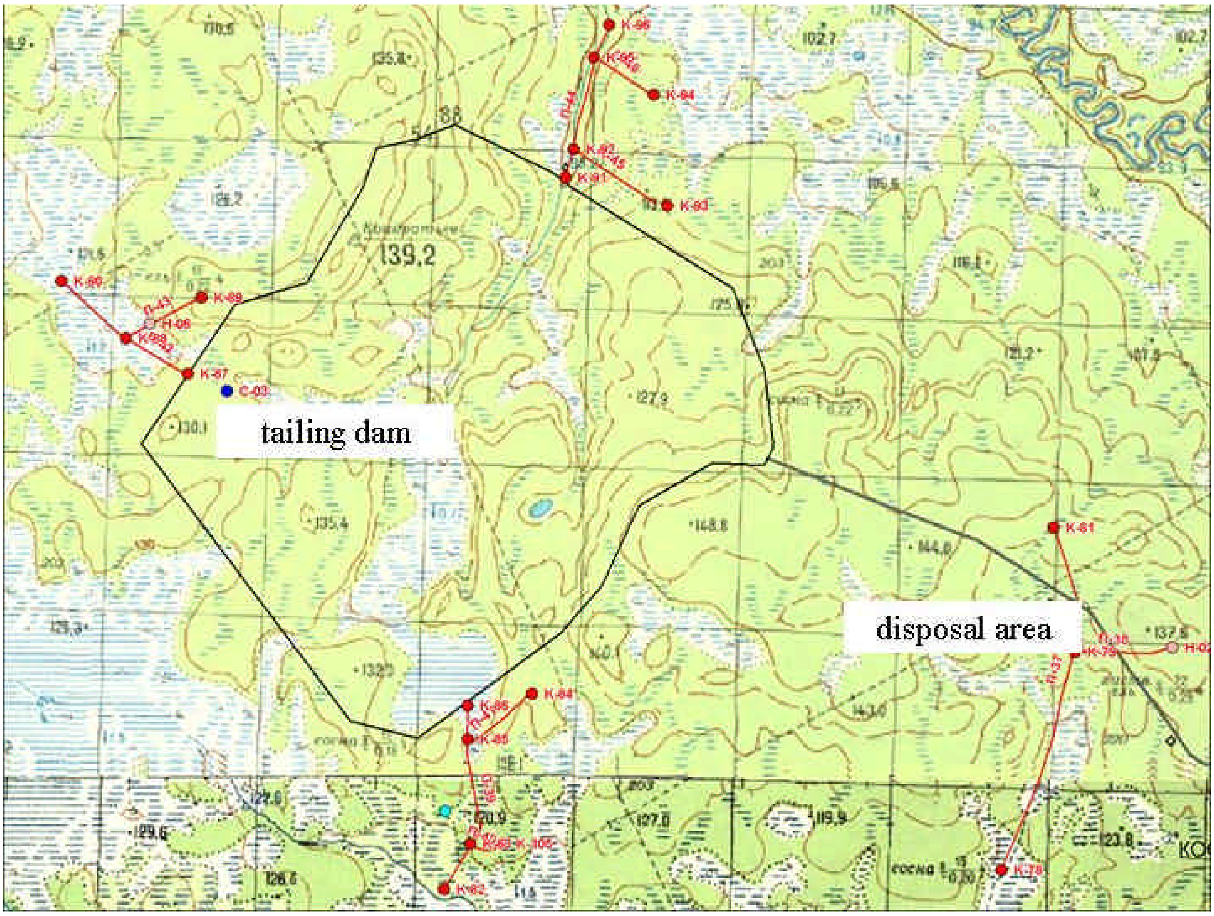
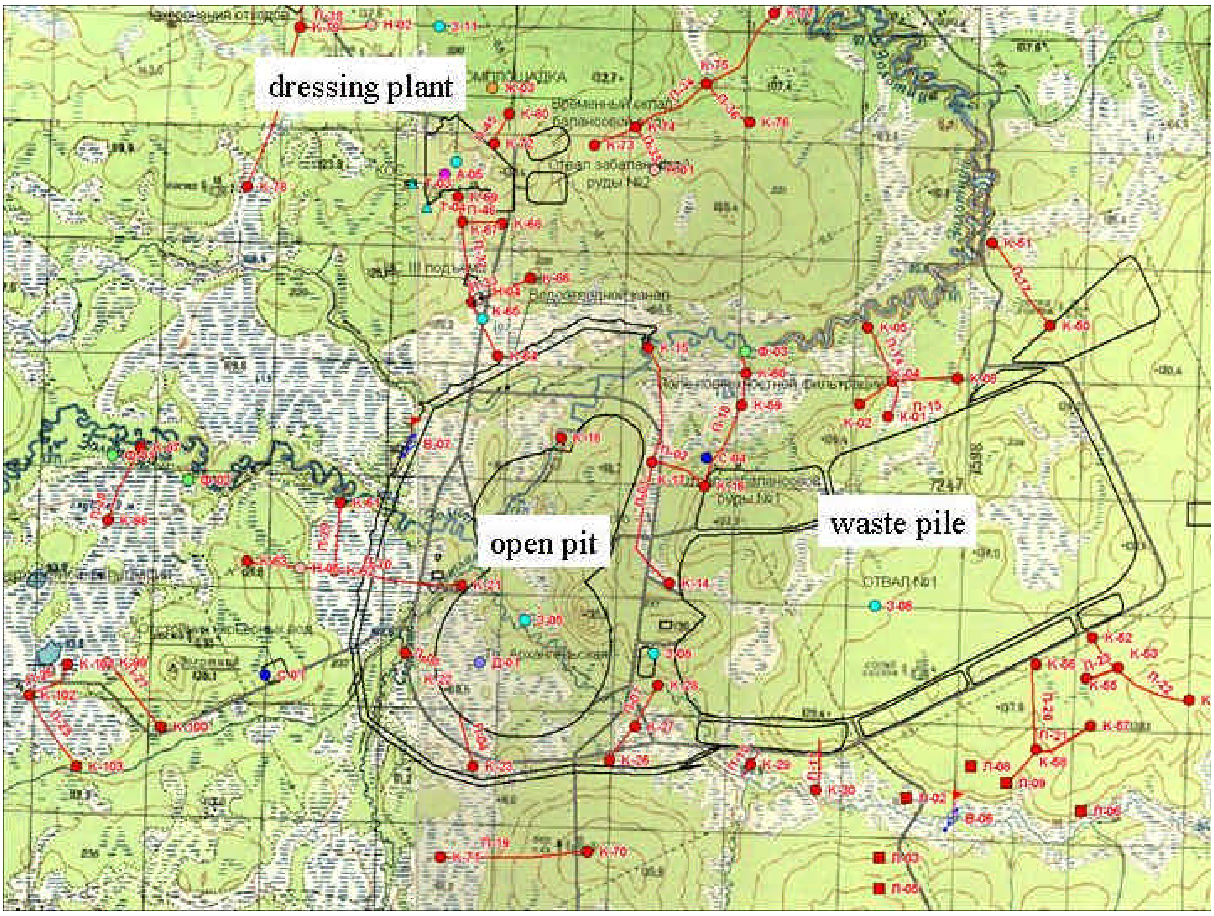


Fig 2. A DMN elements placing scheme (open pit, plant, waste pile).



The IEM system is designed of the whole deposit operating time (approximately 40 yr). It has adaptive properties and will develop as required.

IEM development problems

Specific problems were discovered in the IEM system development. We try to offer approaches to these problems, based on our investigation.

Problem of the monitoring point's location.

A monitoring point is located at a way of influence. Combination of landscape and basin approaches are used for location selecting. Obviously monitoring points cannot control all influence ways. One of the main IEM system problems is to select essential and sufficient quantity of monitoring points. The method to solve the problem is suggested: monitoring points groups are located at main ways of influence, other ways of influence are controled by remote sensing data. In case of large changes on controlled direction, the monitoring network would expand as necessary.

Problem of the monitoring point type selecting.

Another problem is to select monitoring point type and consider natural component interaction. Each monitoring point type is oriented for special impact and change control. Soil monitoring points are oriented on soil changes and integral monitoring points are oriented on the natural components set. One of the methods to solve the problem may be characteristic-indicator search. These indicators are specified for each region and impact type.

Problem of the observation characteristic set selecting.

Observed characteristics of water and air emissions are determined by the pollutant set. Selection of integrated monitoring observation characteristic is more complex. Observation characteristic set selection came from prospective ecosystems changes and the most sensitive environmental elements. Besides, there are monitoring points oriented on the environmental changed flow control (e.g. waste water after bog passing). In that case observation characteristic set should to consider flow changes. In example with waste waters it is exchange reactions within wasted waters, bog and natural bog composition. Modeling and field experiments are needed for those reaction describing.

Problem of measurement frequency

IEM system controlled processes have different rates. So, forest stand growing up changes in first 1-5 years, but ground water levels fluctuations displayed in 10-14 days. Besides, different operating processes also have environmental impact of various intensity. So waste water dropping is every minute process and open pit and depression cone increasing are every day process. Natural and industry multi-rates processes interaction determine problem of frequency observation.

Natural rhythms such as earth revolving also influence on natural processes. Some of the processes need of instant observation, some of them may observe once a year.

At the same time ground water level fluctuations are indicated by vegetation. It is no need to observe ground water level precisely. It is sufficient to find characteristics-indicators that display this process in most completed way.

Problem of natural components interaction at data processing

The first problem is to develop optimal method of data interpolation based on natural components interaction. The second problem is to develop forecasting methods, taking into account natural components interaction. For instance, forecasting of pollutant concentration should consider geochemical exchange within soil and ground water.

Conclusion.

The main principles of rational IEM system develop was determined. They are:

- considering landscape differentiation
- considering of natural components interactions and reaction integrity
- considering primary impact processes
- considering geochemical migration flows

- combination of point-contacted filed researched method and areal remote sensing methods
- integration of analyze and processing data
- using indication characteristic
- adaptivity of structure and work order

The IEM system for diamond deposit on the north of Russia was developed, based on thus principles,. The IEM system consists of approximately 100 monitoring points, 20 routes and profiles and covers the area of 40 sq.km.

The presented IEM structure is to some extent universal and this structure can be applied for different solid mineral deposits.

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