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Integral Monitoring as a Tool for Environmental Security

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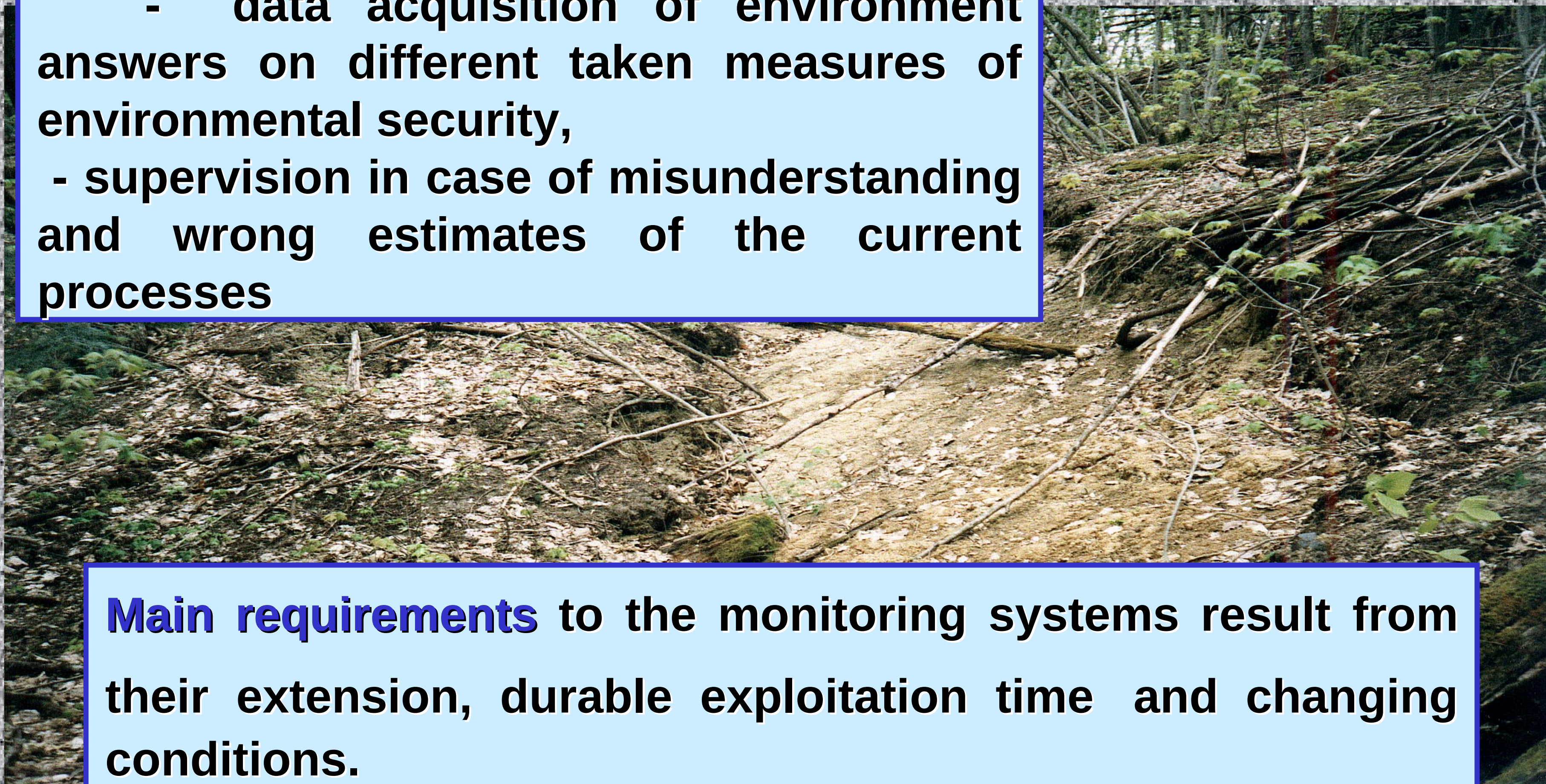
The goal of report

The goal of report is to discuss problems of monitoring systems development and ideas for their decision.

The present report is based on designing experience of monitoring systems for large constructions. The Institute of Environmental Geoscience took part in designing projects of environmental monitoring for gas pipeline "Blue Stream", "Megaproject Yamal", "Sakhalin-2".

The environmental monitoring deals with **following tasks:**

- environmental data acquisition; these data are the base for prognosis of processes and analysis of their sources,
- data acquisition of environment answers on different taken measures of environmental security,
- supervision in case of misunderstanding and wrong estimates of the current processes

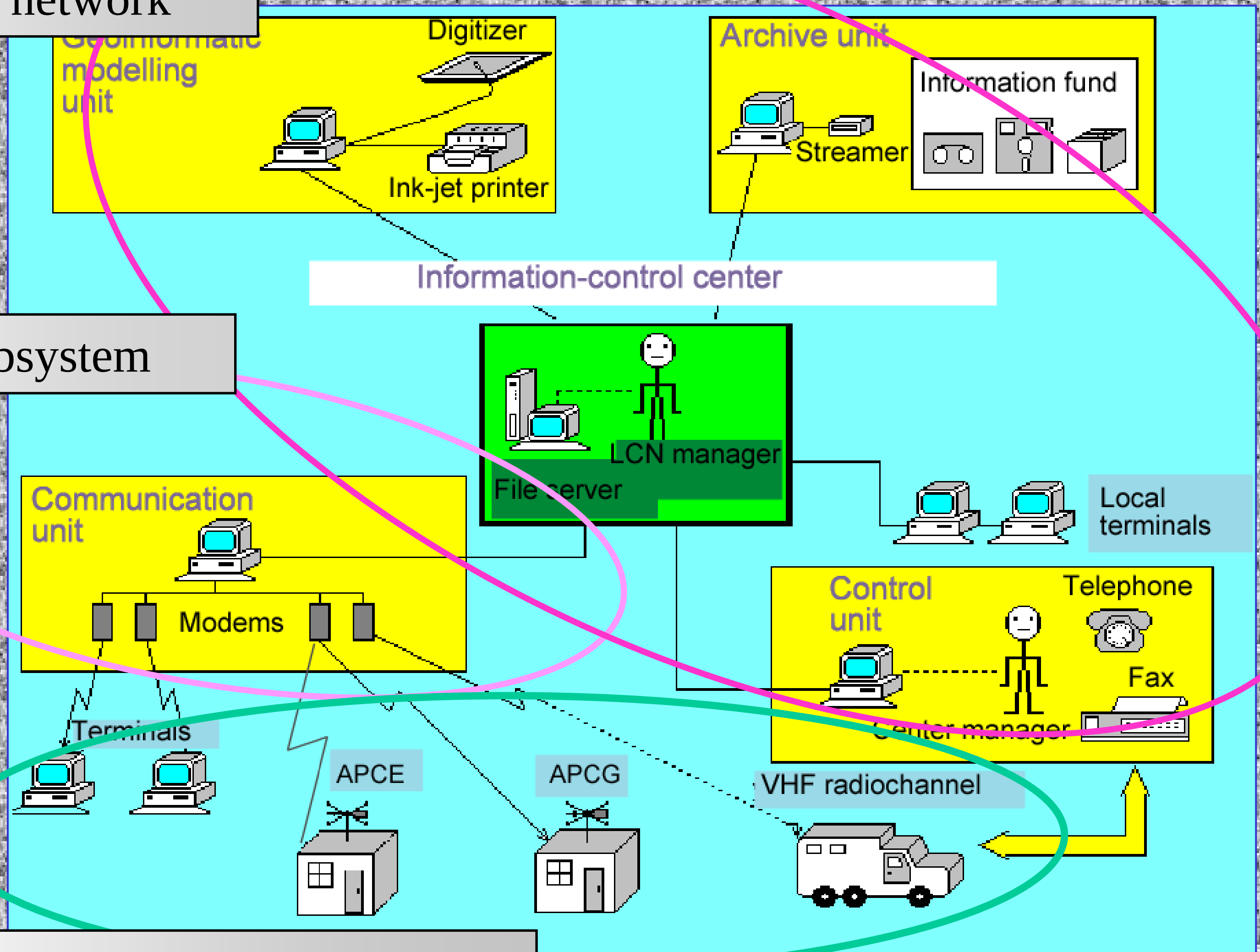


Main requirements to the monitoring systems result from their extension, durable exploitation time and changing conditions.

Structure of the Monitoring System

❖ Data-managing network

❖ Data transfer subsystem

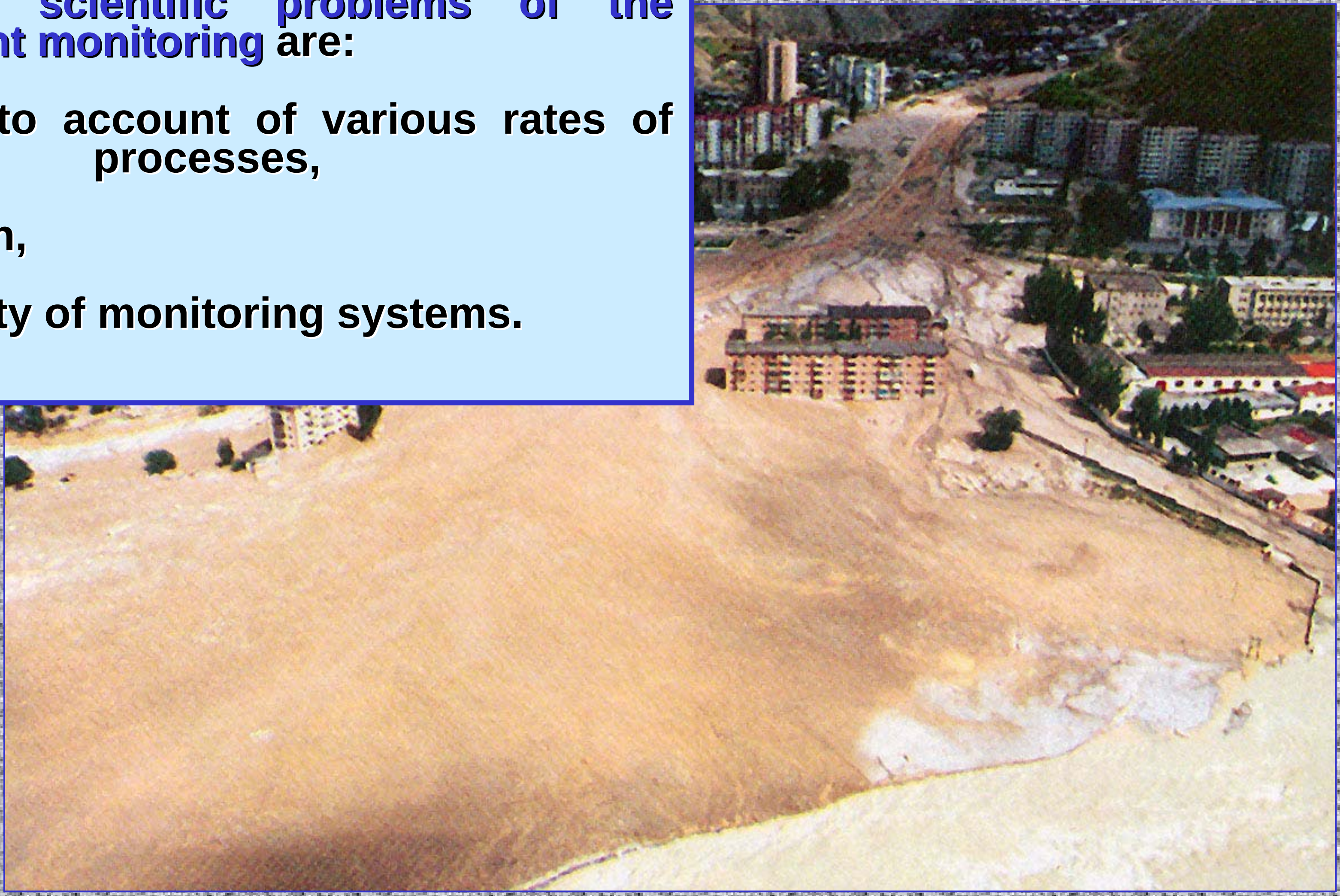


❖ Data-measuring subsystem (network)

The main scientific problems of the environment monitoring

The main scientific problems of the environment monitoring are:

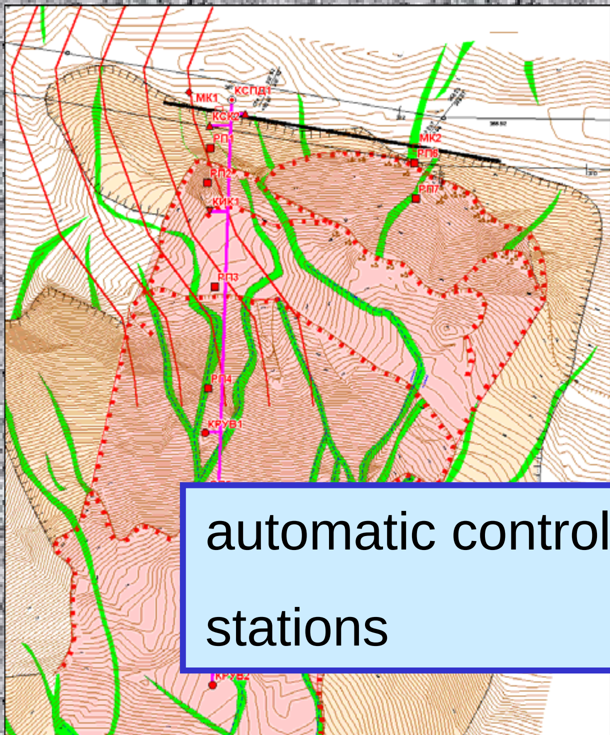
- taking into account of various rates of different processes,
- integration,
- adaptability of monitoring systems.



The problem of various rates of different processes

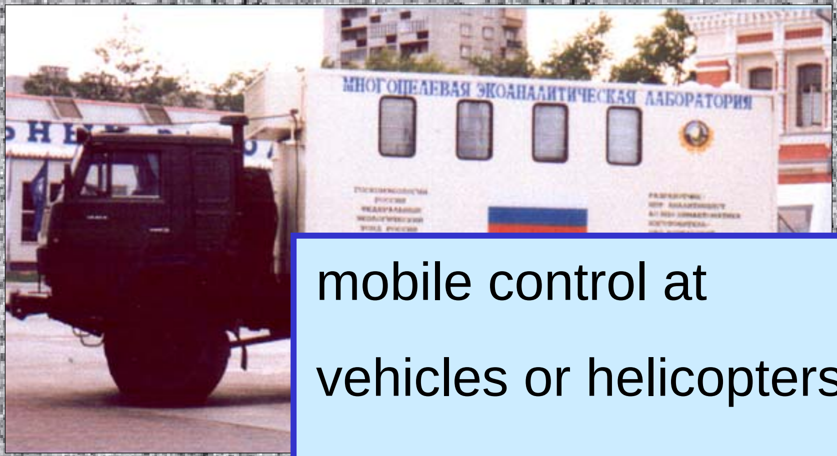
The problem is that the monitoring system should control the processes with different rates.

Data-Measuring Network

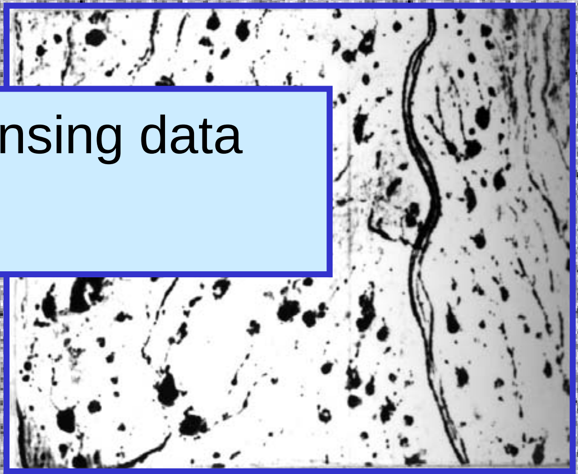


automatic control stations

visitation control stations



mobile control at vehicles or helicopters



remote sensing data

Automatic control stations are used for ground spot monitoring of rapid processes

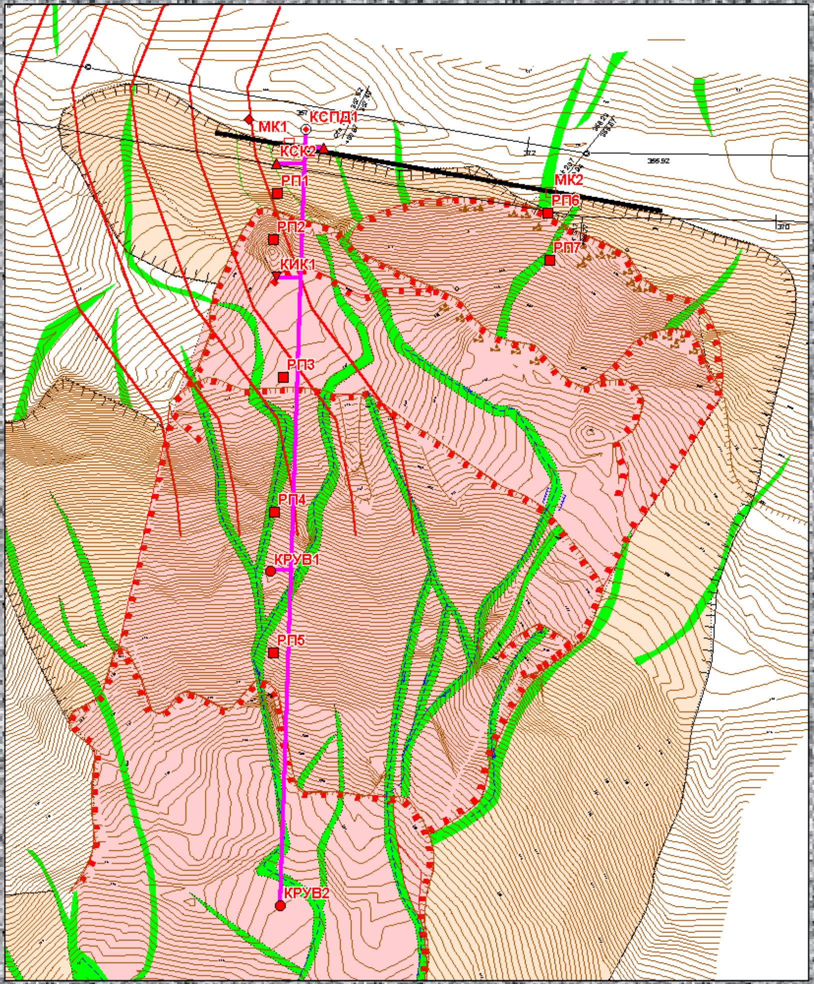
The Posts of Automatic Landslide Control

These posts provide the control for the following parameters:

- *the groundwater level*
- *the seismic acoustic emission level*
- *the rock mass movement (the position of the lengthwise inclinometer axis)*

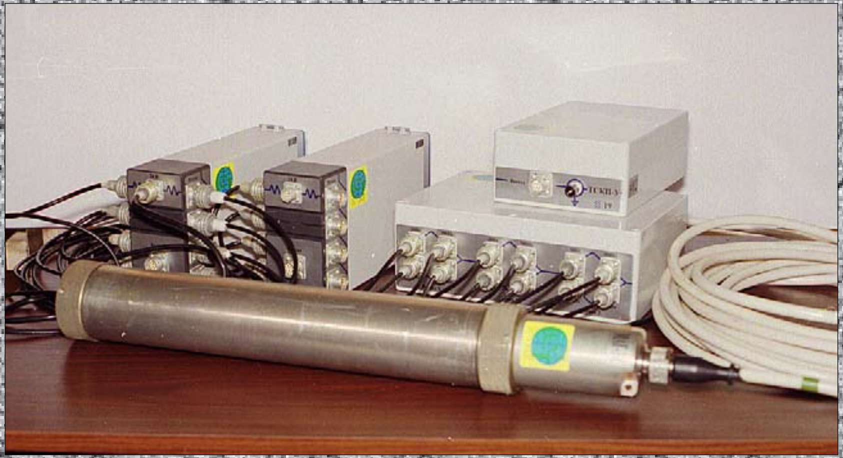
The Posts of Automatic Landslide Control

The Control Units



a seismic acoustic control unit
a inclinometric control unit
a groundwater level control unit

Equipment of the Posts of Automatic landslide control



Seismic Acoustic Control Complex

Sensing Units

A groundwater level control unit

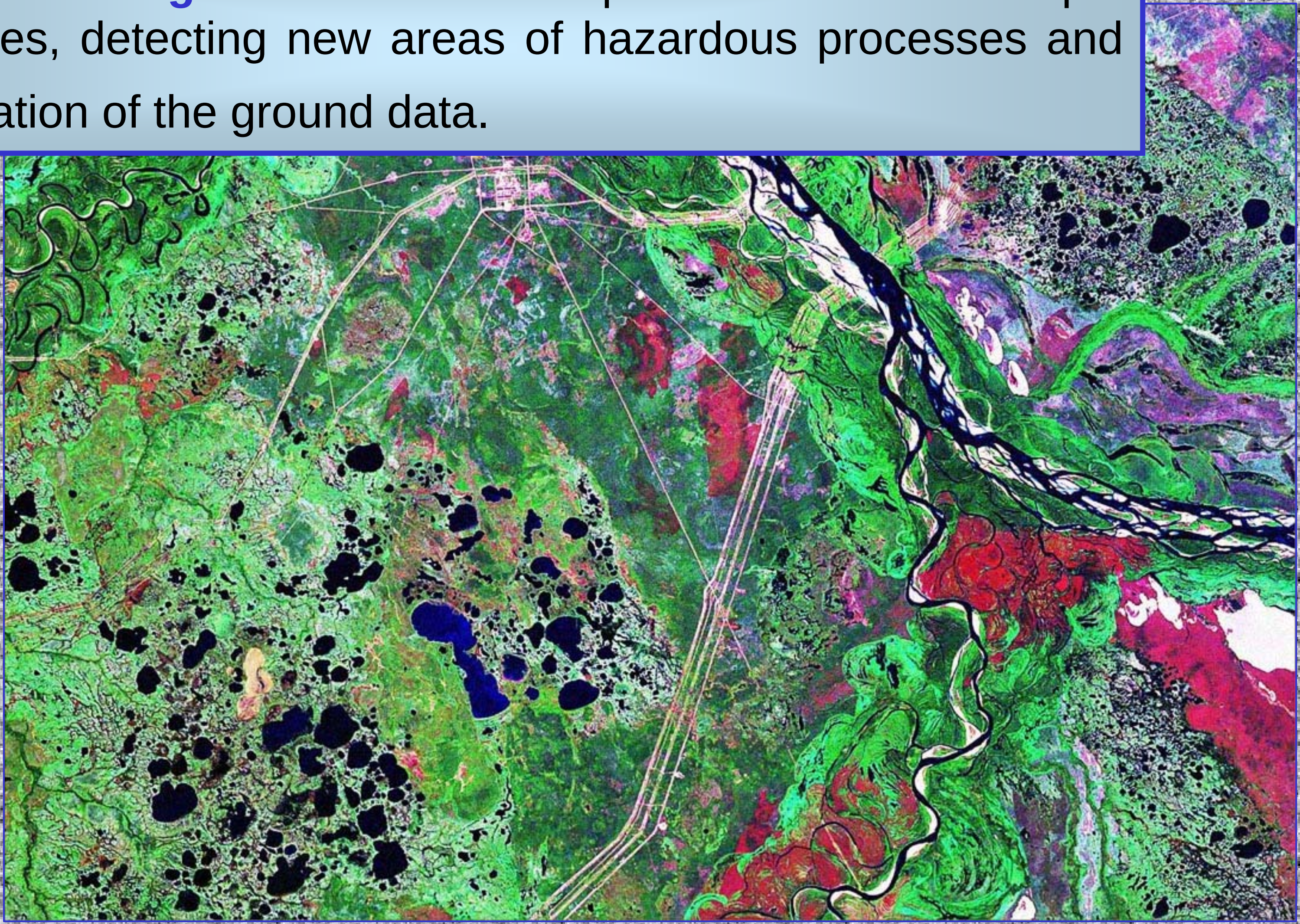
An inclinometric control unit

The equipment is produced by a department of the Institute of Environmental Geoscience and has the State Certification.

Equipment of an automatic seismic control station for off-shore platform

Remote Sensing Control

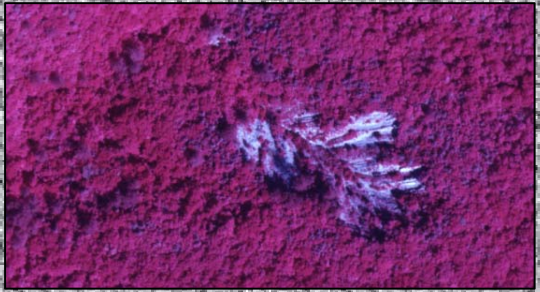
Remote sensing data are used for spatial control of non rapid processes, detecting new areas of hazardous processes and interpolation of the ground data.



Landslide Remote Control

Landslide

Erosion Sliding Circus



Waterlogged Areas

In image interpretation, the indicative principles permitting us to obtain data on environment components using indirect signs.

The problem of integration

Additional complication of monitoring tasks results from interrelations between different nature components, such as atmosphere, surface and groundwater, vegetation, soils, and others.

The problem of integration deals with spatial and time optimization of measurement mode for controlling a set of interrelated but different nature components with different variability.

This problem can be solved using the following approaches:
- using combined control stations,
- choosing parameters taking into account indicative characteristics of a landscape, vegetation first of all.

Structure of the Data-Measuring Network (an example)

integrated environment control stations (types 1,2, and 3)

cross-sections of integrated nature environment control

control stations of surface water

stations and routes of aquatic biota and land fauna control

stations of waste water control from factories, quarries, and filtration fields

stations of waste and drained water control

stations of gas emissions and air pollution control

remote sensing data

The problem of adaptability

The problem of adaptability concerns structure and operating changes of the monitoring system according to changing nature environment.

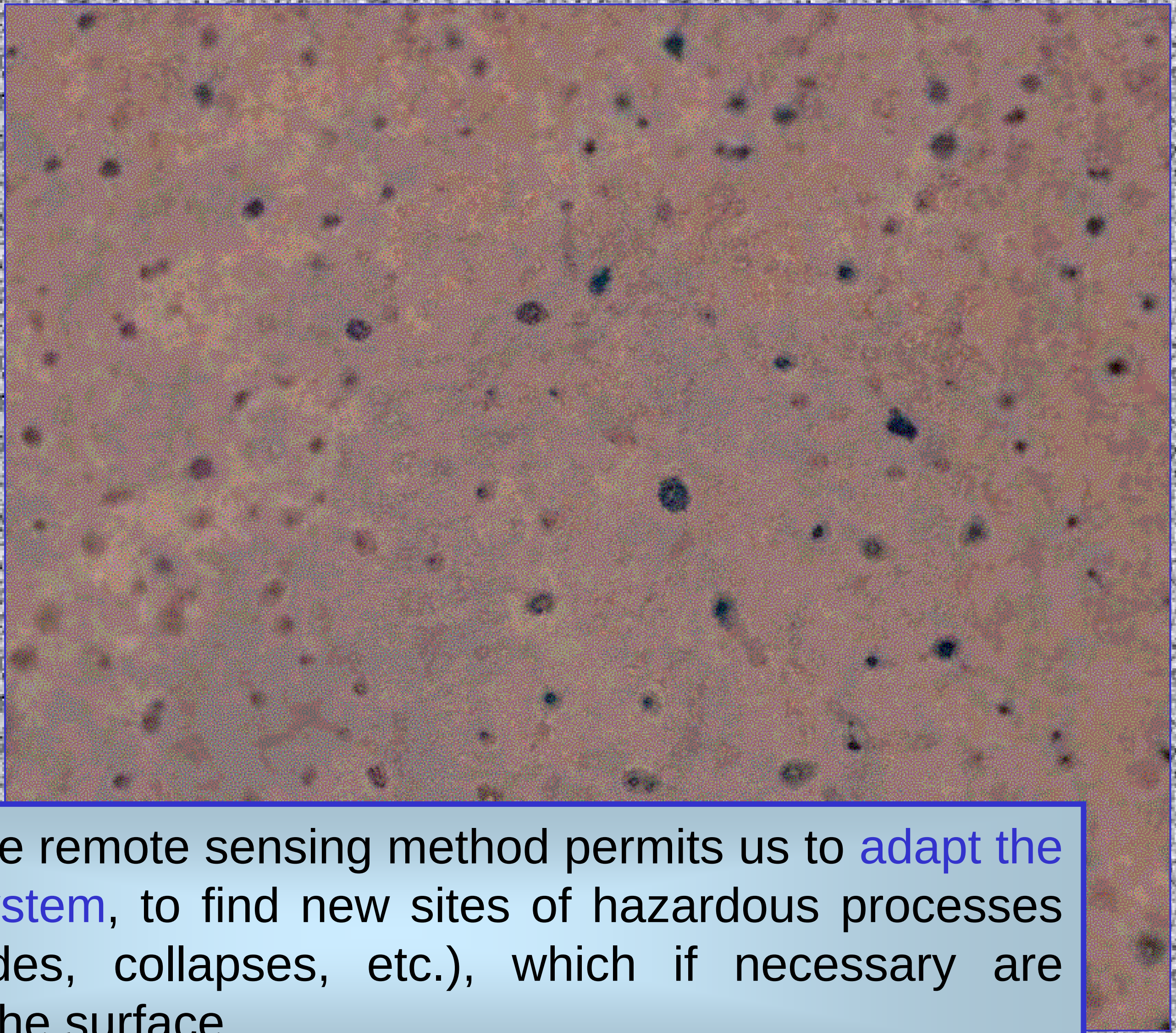
This problem can be solved using adaptive mobile pattern, including:

- Adaptive schedule,
- Adaptive indicative control stations,
- Remote sensing data.

Main adaptive procedures in operating mode of an Industrial Environmental Monitoring System (an example)

Number	Changes of the Environment	Changes of IEMS pattern or schedule
1	Increasing concentration of pollutants at points K-87, 90	Design of a new control station of surface water B-11 with a schedule similar to B-1
2	Consistent solid residual increasing at station D-1 more than 1 mg/l	Schedule change at station D-1: including macro components (strontium, lanthanum, and titanium) into the list of controlled parameters
3	Lanthanum, strontium or titanium occurrence at station K-65	Schedule change at stations K-64 and H-4: including the same components into the list of controlled parameters

The problem of adaptability



In addition, the remote sensing method permits us to adapt the monitoring system, to find new sites of hazardous processes (new landslides, collapses, etc.), which if necessary are controlled at the surface.

The Thermokarst Plains with Fluvial Erosion

The thermokarst plains with fluvial erosion are slight wavy subhorizontal areas covered by tundra vegetation, interspersed with lakes and khasyreis (a khasyrei is a drained lake) and rather rare fluvial erosion network.

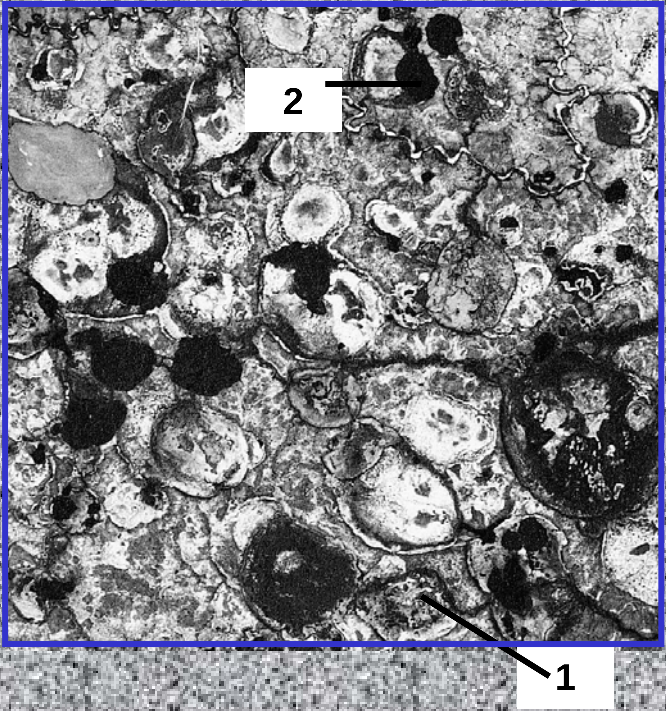
The main parts of the region include:

- flat tundra plain,

- thermokarst lakes,

- khasyreys,

- fluvial erosion network.



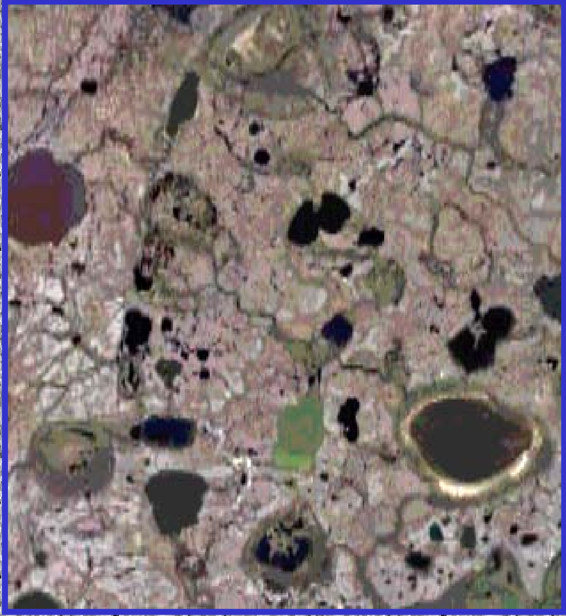
An air-borne photo of such landscapes
1 – khasyreys, *2* – thermokarst lakes .

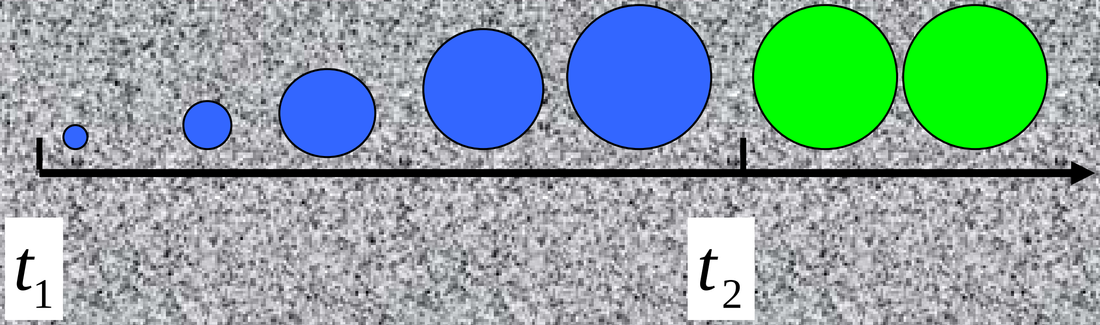
Evolution of a Thermokarst Depression

Thermokarst, thermo-abrasion, and thermo-erosion processes exist in complex interrelations and determine the type of the area.

Every thermokarst depression passes through the following stages:

1. **Origin of depressions**
2. **These depressions are filled up with water as lakes and increase in size independently of each other due to thermo-abrasion process.**
3. **Occasionally any lake can be drained due to erosion process and turn to a khasyrei. The size increasing stops.**

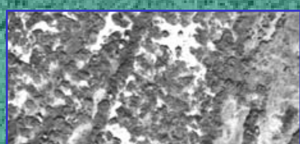




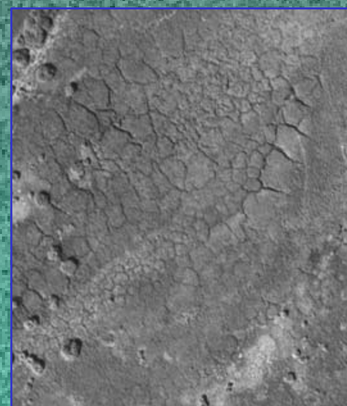
The mathematical morphology of landscape is a new scientific branch studying both numerical regularities (laws) of **landscape patterns** and methods of their mathematical analysis.

The basic concept of mathematical morphology is a mathematical model of a landscape pattern.

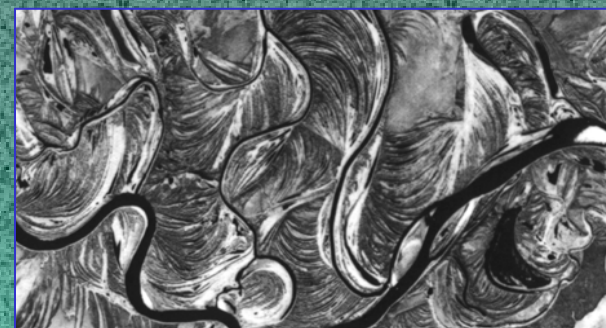
Deflation Hollows



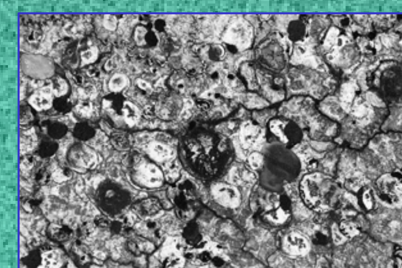
Frost-Clefts



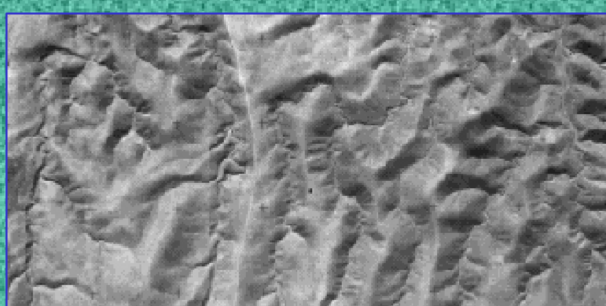
Alluvial plain



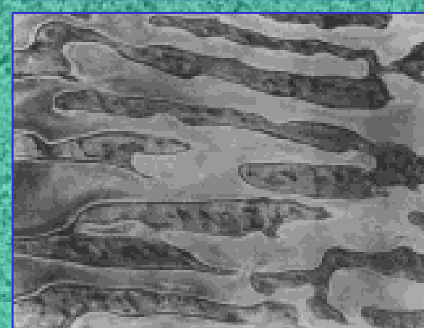
Thermokarst Plains with Fluvial Erosion



Erosion plain



Ber hills



Thermokarst Plains with Fluvial Erosion Network: Assumptions of the Model

1. Appearance of a thermokarst depression within every taken area is an occasional event, which probability is directly proportional to the size of the area.

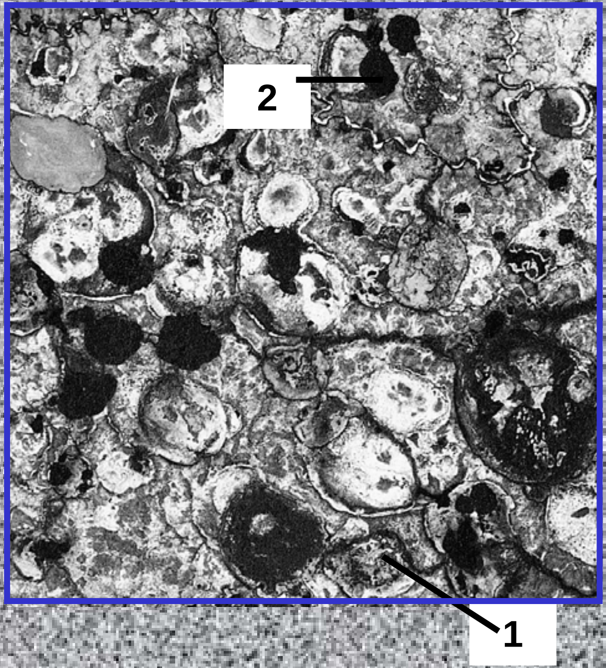
2. Radius of an initial thermokarst depression is a random variable with distribution density $\varphi(v)$.

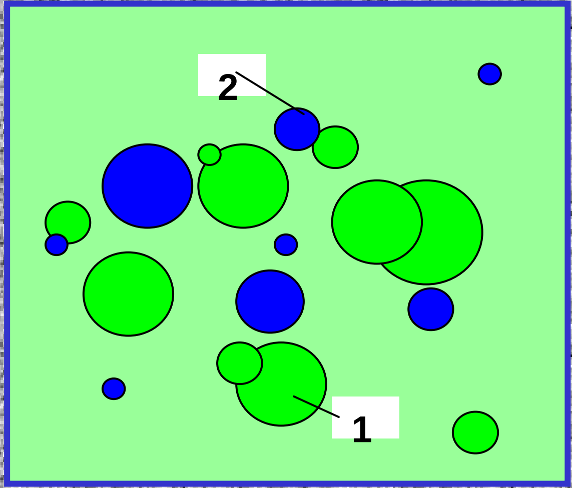
3. Growth of an appeared thermokarst depression is a random variable; it is independant of other lakes and the growth rate is directly proportional to heat storage in the lake water; it is inversely proportional to the total surface area of the water body.

4. Depth of a lake is in direct proportion to its diameter.

5. In the course of its growth, a lake can turn into a khasyrei after draining by the fluvial erosion network; probability of this does not depend on development of other lakes. If it happens the depression stops to grow.

6. Appearance of new sources of erosion forms within an occasional area is a random quantity, which probability is directly proportional to the size of the area.

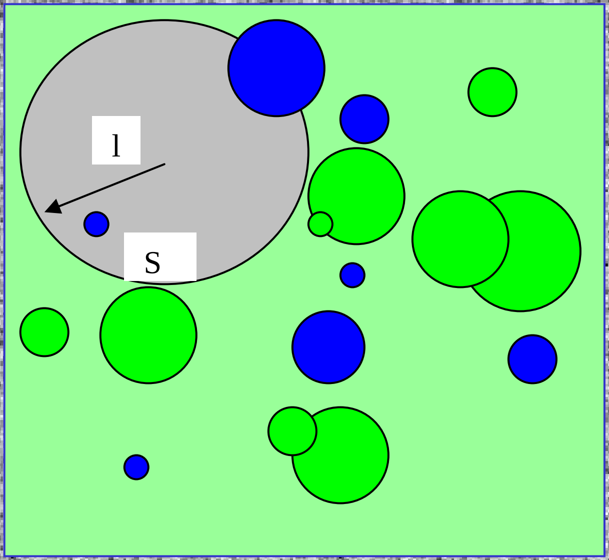




1 – khasyreis, *2* – thermokarst lakes .

Nature Hazard Evaluation and Estimation of Possible Impact on Engineering Constructions

Thermokarst Process Impact on Areal Constructions

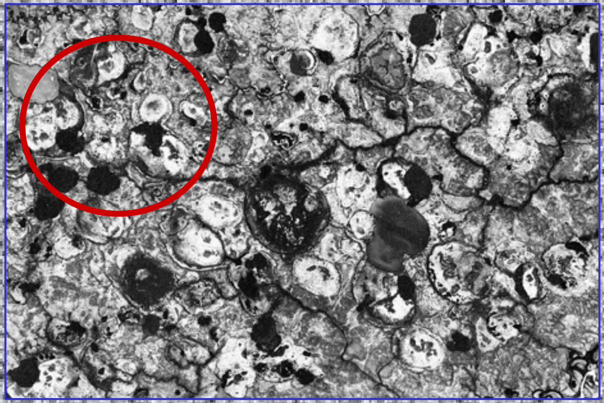


An impact probability for a round plot of given area (*l*) with kernels

$$P_{ds}(l) = 1 - e^{-\pi\gamma(t)[(\bar{r}(t)+l)^2 + \sigma_r^2(t)]}$$

An average risk for areal constructions of area S

$$R_s(l) = \pi[1 - e^{-\pi\gamma(t)[\bar{r}(t)^2 + \sigma_r^2(t)]}]l^2$$



where $\gamma(t)$ **is an average number of kernels per area unit,**

$\bar{r}(t)$ **is an average radius of kernels,**

$\sigma_r(t)$ **is standard deviation**

Nature Hazard Evaluation and Estimation of Possible Impact on Engineering Constructions

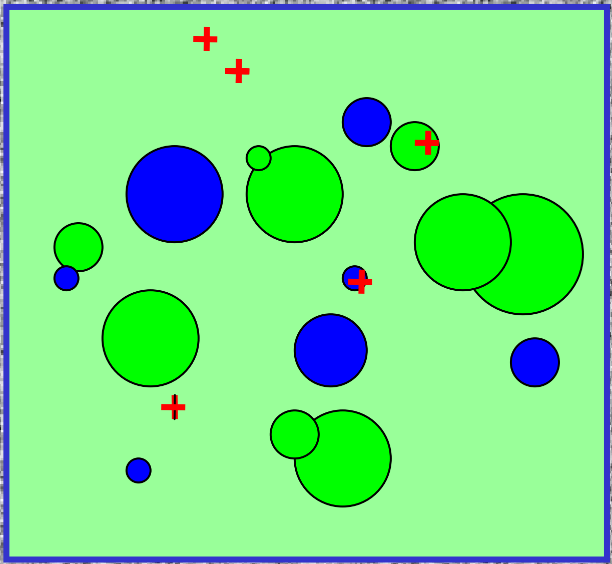
Empirical Testing

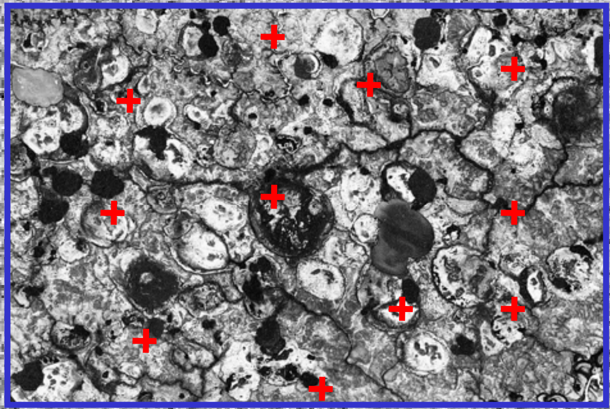
An Impact Probability for Round Plots of Different Size (South of the Western Siberia)

Size of a plot *l*	Theoretical probability	Empirical friquency	Difference
10	0,367	0,393	0,026
20	0,477	0,505	0,028
30	0,582	0,639	0,057
40	0,677	0,75	0,073
50	0,76	0,835	0,075
60	0,826	0,882	0,056
70	0,878	0,916	0,038

Nature Hazard Evaluation and Estimation of Possible Impact on Engineering Constructions

An Thermokarst Process Impact on Small Areal Constructions (a point unit)





A probability of a process impact at moment t

$$P_d(t) = 1 - e^{-\gamma(t)s(t)}$$

A probability of an impact with two types of the sites

$$P_d(t) = 1 - e^{-\gamma_1(t)s_1(t) - \gamma_2(t)s_2(t)}$$

where $s(t)$ **is an average area of the sites at moment t,**
$\gamma(t)$ **is an average number of the sites per area unit,**

Nature Hazard Evaluation and Estimation of Possible Impact on Engineering Constructions

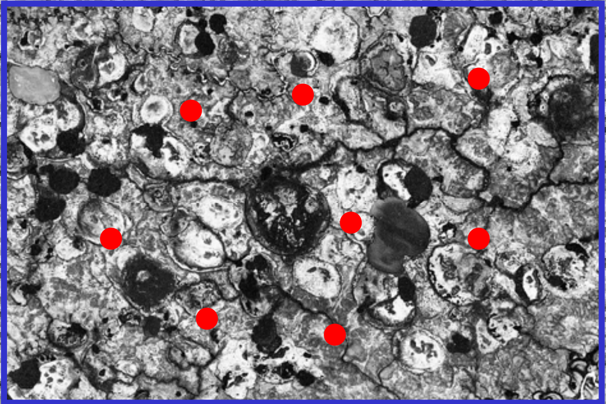
Empirical Testing

1. Theoretical calculation:

Average density of khasyreis
Average area of khasyreis
Average density of thermokarst lakes
Average area of thermokarst lakes
Formula of impact probability for a point unit

2. Empirical probability

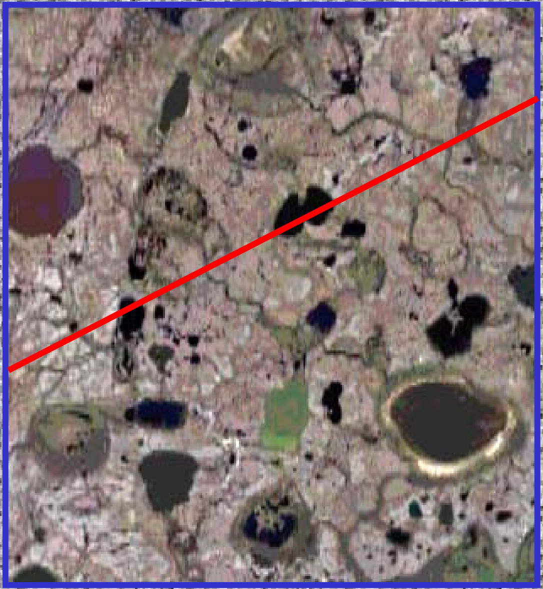
Generation of coordinates of random points
Mapping points at an experimental plot
Direct counting a number of impacts



Parameter	Value
Theoretical impact probability for a point unit	0,451
Empirical frequency of impact on a point unit	0,440
A number of samples	100
Acceptable deviation at 0,95	0,10

Nature Hazard Evaluation and
Estimation of Possible Impact on Engineering Constructions

Evaluating parameters for risk assessment basing on repeated remote surveys. An example of Thermokarst-Erosion Plain.



An impact probability for a linear construction of length L

$$p(t) = 1 - [1 - p_1(t)][(1 - p_2(t)]$$

$$p_1(t) = \prod_{i=1}^{m} [1 - q_i(t)] \qquad p_2(t) = 1 - \exp[-2\beta(t)\lambda(1-P)L]$$

$$q_i(t) = \exp[-\pi\gamma(r_i^2 - v_i^2)] \int_{r_i}^{+\infty} \frac{1}{\sqrt{2\pi}\,\sigma u \sqrt{t}} \exp[-\frac{(\ln u - \ln v_i - at)^2}{2\sigma^2 t}] du$$

$$\beta(t) = \frac{t}{2\sqrt{\gamma}} - \int_0^{+\infty} \exp(-\pi\gamma x^2) \int_0^t \hat{O}\left(\frac{\ln x - au}{\sigma\sqrt{u}}\right) du dx$$

where

$a, \sigma, m, v_i, r_i, \gamma, \lambda$ **are parameters,**

t **operation time of the construction**

Nature Hazard Evaluation and Estimation of Possible Impact on Engineering Constructions

Evaluating parameters for risk assessment basing on repeated remote surveys. An example of thermokarst plain with fluvial erosion.

The parameters included in the calculation equations may be obtained from the repeated remote surveys

Evaluating initial parameters of the model

$$a = \frac{M_2 - M_1}{t_2 - t_1}, \quad \sigma = \sqrt{\frac{D_2 - D_1}{t_2 - t_1}},$$

$$\lambda = \frac{(n_2 - n_1) + (m_2 - m_1)}{(t_2 - t_1)(S - S_t)}, \quad P = \frac{S_t}{S}, \quad \gamma = \frac{\varepsilon}{S}$$

where

$t_1, \ t_2$ -is the time of the first and second surveys,

$M_1, \ M_2$ -is the average radii logarithm of the thermokarst sites (lakes) within the testing area at the corresponding date of survey,

$D_1, \ D_2$ -is the logarithm radii variance for thermokarst sites (lakes) within the testing area at the corresponding date of survey,

$n_i, \ m_i$ - numbers of active thermokarst sites (lakes) and correspondingly degenerate sites (khasyreis) within the testing area at the corresponding date of survey,

S - is the total testing area, S_i is the part of the testing area occupied with the thermokarst sites,

ε - is the number of fluvial sources within the testing area.

The monitoring system is based on the following principles:

- The system executes the combined control over the entire set of observed parameters.
- The measurement system combines contact and remote control techniques permitting continuous area coverage and observation extrapolation.
- The system uses method of obtaining and processing data based on the existing relationships of different natural components (including wide use of indicative properties of vegetation).
- The system takes into observation the processes with different rates – from high to low.
- The structure and operation of the environmental monitoring system are adapted to the modifying environmental conditions and construction development.

Management Problems

Two levels of environmental monitoring are in Russia:
- State monitoring
- Local monitoring

Local monitoring systems control limited areas. At the same time they provide for comprehensive control and get important data for general assesses. According to the Russian legislation local monitoring systems are organized and operates at business owner cost.

Conclusions

1. Monitoring is one of the key units ensuring environmental safety.

2. Monitoring should be integrated and comprehensive and control different nature components, such as air, vegetation, hazardous geological processes, and others.

3. General environmental monitoring should unite both the State system and local systems of environmental monitoring.