

Development of the open drainage network of St. Petersburg suburbs on the basis of GIS technologies

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Abstract. The article discusses the methodology of solving problems associated with the forecast of the future state and ways of development of open drainage networks, which includes: assessment of the current and future state of open drainage network, calculation of the potential economic damage and prioritizing of repair works on the elements of open drainage network. These solutions were used to forecast the development of open drainage network of St. Petersburg suburbs.

1. Introduction

With a view to develop the measures of reconstruction of the open drainage network in the area immediately adjacent to St. Petersburg (within the city administrative boundaries), the St. Petersburg administration has commissioned to carry out works on assessment of the present state of the main drainage channels and hydraulic structures located on them.

In the period since the early 60's to mid 80's last century, there was an intensive development of agricultural production in the Leningrad region and, in particular, in the area directly adjacent to Leningrad. One of the methods to increase the productivity of agricultural land was the construction of drainage systems to improve the conditions of crop development by limiting the soil moisture. In the early 90's, the construction of new drainage systems was stopped. In the early 2000's, the areas directly adjacent to St. Petersburg faced a boom in construction of industrial facilities, highways, private housing and cottage building. So, these problems arise due to the lack of the integrated systems of administrative decision-making [1], and also demands the solution of problems with treatment of megacities land drainage and land runoff features [2, 3].

The zones allocated for the transport, industrial and residential facilities were, in many cases, located in areas of former drainage systems. This loss of functionality of drainage systems occurred not only in the areas of construction sites, but also in the upstream drainage zone. The repair and refurbishment works at the drainage reclamation systems in the period of 1990-2010 were mainly focused on maintaining of the minimal required operation of basic elements of the systems, which include the main drainage channels: trunk channels, transporting collectors, open collectors.

As a result, to date, the open drainage network (a complex channels and hydraulic structures) is



characterized by partial loss of functionality and, as a consequence, the elevated groundwater levels. Many cities and municipalities face such problems [4-7]. The impacts and the resulting problems are described in [8, 9].

2. The technique works

This paper presents an approach to solving problems associated with the forecast of the future state and ways of development of open drainage network, which includes:

- assessment of the current state of the open drainage network (land use and technical condition);
- assessment of the prospective use of the open drainage network;
- calculation of the potential economic damage resulting from the lowering of performance of each channel;
- sequencing the repair and refurbishment works on the elements of the open drainage network or the absence of the need for reconstruction.

There are several methods for assessing the risk and damage from flooding [10-16].

The proposed methodology consists of three main sections – field survey of the open drainage network, creation of GIS system, analysis of the results [17] – and includes several consecutive stages:

- interpretation of satellite images to determine the location of drainage systems and their mapping;
- determination of the areas boundaries (according to the results of interpretation) where the aerial photography of drainage channels should be carried out;
- digital aerial photography of the areas with the identified systems of channels, with subsequent topographic binding of aerial photographs to the digital map;
- field survey of the open drainage network;
- integrated assessment of the state of the trunk channels and adjacent areas;
- economic assessment of damage from the unsatisfactory condition of trunk channels;
- identification of areas that require first priority measures to restore the integrity and water conveyance capacity of drainage channels.

Below, you can find the discussion of the stages of works in several districts of St. Petersburg

3. Works on the Open Drainage Network of Saint-Petersburg suburbs

The works were carried out on the territory of several districts of St. Petersburg, both in the agricultural territories and in the developed or built-up areas: Kurortny, Primorsky, Vyborgsky, Kronshtadtsky. The works affected both the resort construction areas and forestry areas of St. Petersburg: Pesochinskoye, Sestroretskoye, Primorskoye and Molodezhnoye.

For the purposes of channels interpretation, the researchers have used publicly available data of Google maps and Yandex.Maps. Then, the researchers used the software of ESRI ArcGIS Desktop

10.0 to perform scaling and binding of the images to Gauss Kruger coordinate system used by the City. According to the results of interpretation, the researchers identified the main channels and areas that should get a more detailed aerial photography. An example of satellite images processing is presented in Figure 1.

The total number of channels detected during interpretation is 12119 channels with a total length of 2502 km.

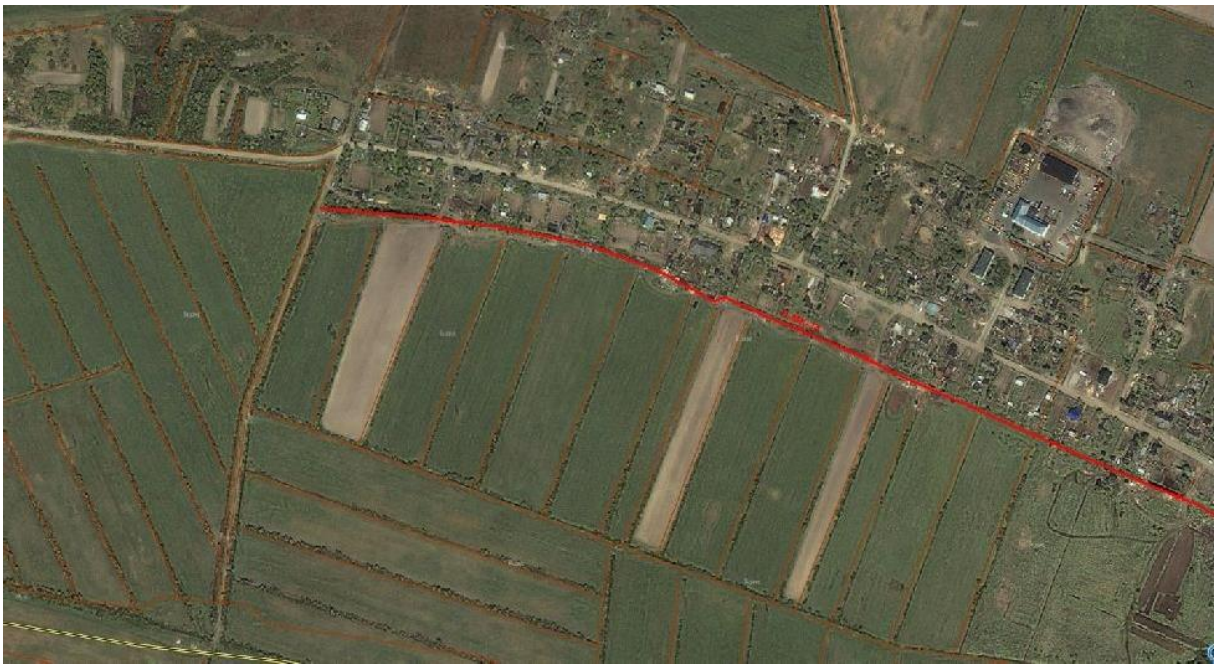


Figure 1. Interpretation of satellite images

In the next stage the researchers obtained sets of actual map-boards of aerial photography. The images make it possible to identify the channels by their type and to determine the main parameters: length, width, availability of pipeline crossings. Figure 2 presents the methodology for identification of channels using aerial photography on the example of the Kurortny district.

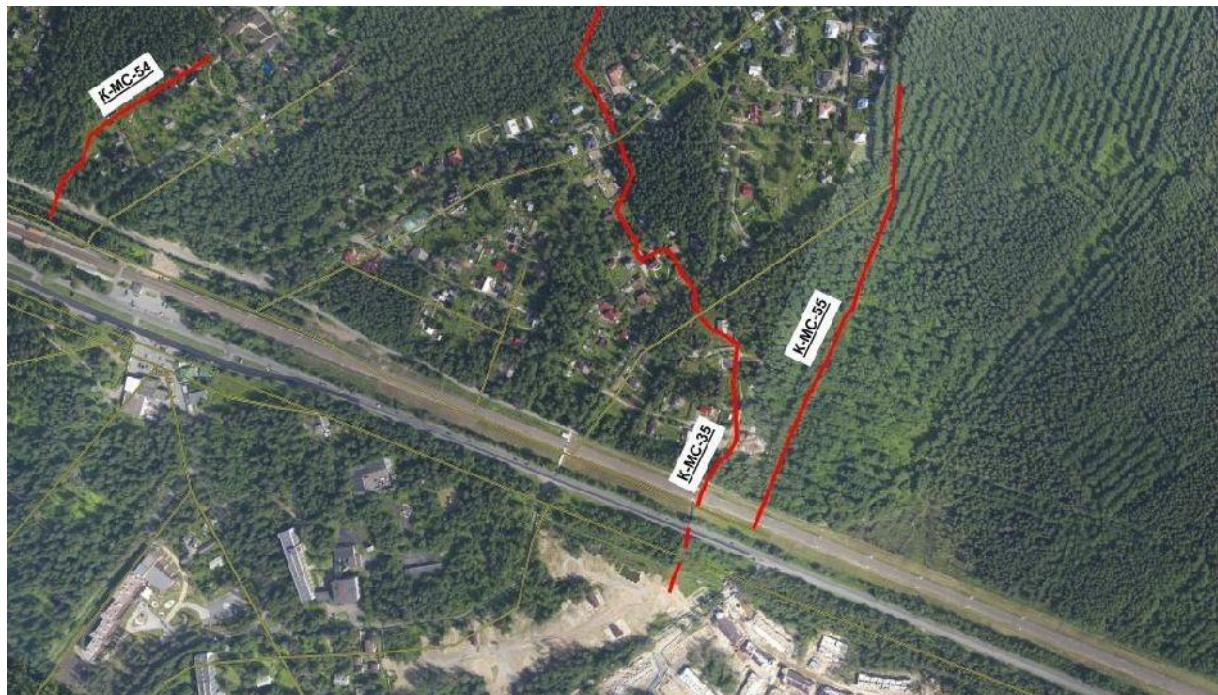


Figure 2. Aerial photo of part of Kurortny district

The location and parameters of minor channels were more precisely specified by topographic map-

boards (Figure 3).

After a comprehensive study of maps and aerial photographs, the routes of field surveys were defined.

During the field survey, the researchers identified the main parameters of trunk channels: length, width at the top, width along the bottom, depth of the channel, depth of water in the channel, average speed, state of the bed, availability of wetland areas in the drainage basins of channels, causes of soils waterlogging, siltation of channels, places of destruction of channels lining, destruction of slopes, destruction of craters, crossing of utilities lines, size of land lots allocated for temporary and permanent use, conformity of the lands allocations to the land regulations, drainage basin. Also the researchers examined pipeline crossings on trunk channels and filled the registration forms that contain: name of the channel, length and diameter of pipeline crossing, condition of head walls.

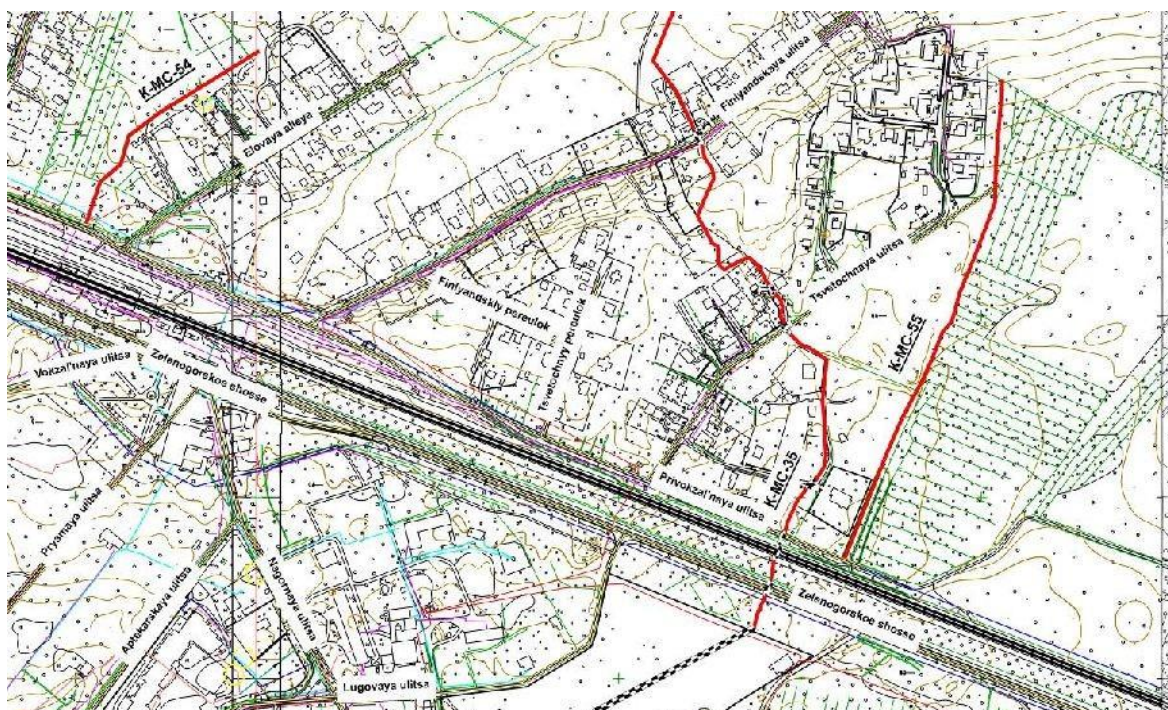


Figure 3. Precise specification of channels boundaries by topographic map-boards

For each of the trunk channels, the researchers determined the width of lands allocated for permanent and temporary use in accordance with the regulations for land allocation for open drainage channels.

The researchers designed and created the structure of geographic information system in the ArcGIS Desktop 10.0 software. This system is widely used for resolving the problems of environmental regulation, assessment of flood-prone areas and evaluation of environmental quality [18-21].

The created GIS contains the following data layers: Channels (linear features); Pipeline crossings (point features); Points of craters destruction; Points of slopes destruction; Points of destruction of slopes lining; Wetlands areas; Crossings with engineering networks; Points with no movement of water; Points vegetal invasion of channel beds; Wet spots; Drainage basins of trunk channels; Points with violation of hydrological regime; Bridges.

In addition, 697 photos that reflect the state of open drainage systems facilities were uploaded to ArcGIS.

The shape format was selected as the vector format of spatial data. The spatial data were created in the locally used coordinate system - Gauss Kruger projection. All information from the registration forms was entered into the attribute tables of the respective data layers.

The layer of open drainage channels contains channels of the following types: Trunk channels (TCh);

Transporting collectors (TC); Open driers (OD); Roadside ditches (RD). Such a composition is caused by the absence of more detailed information about the types of channels in these areas. On the basis of the developed GIS, the researchers completed the registration forms containing information about the channel parameters measured during field surveys. During the field surveys, 110 trunk channels were identified. Also, as a result of the field surveys and analysis of topographic map-boards and images, the boundaries of drainage basins of the trunk channel were identified (Figure 4).

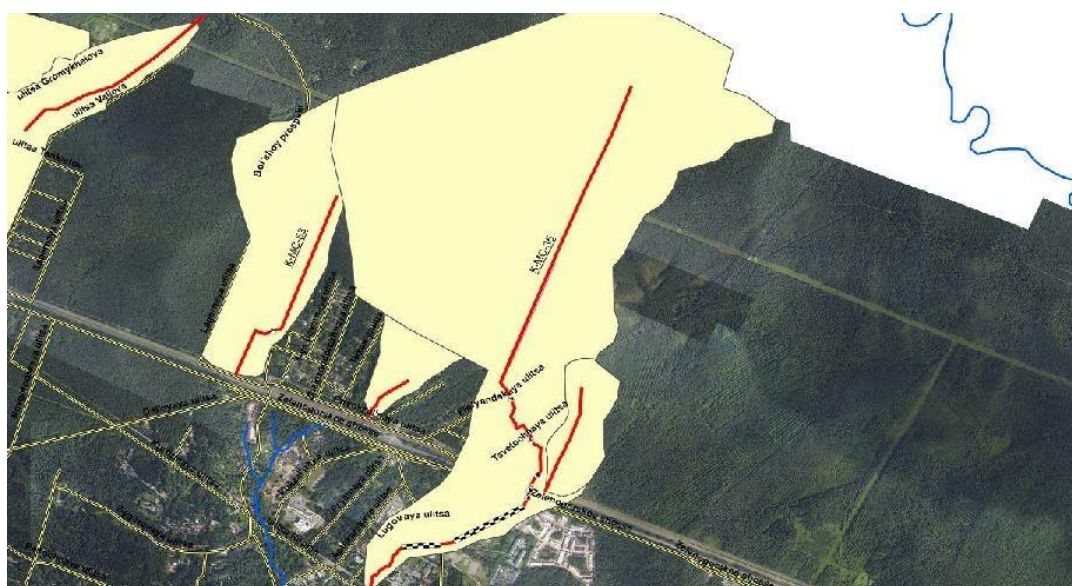


Figure 4. Construction of drainage basins of trunk channels Analysis of the field survey results showed

- present and future land use structures are presented in tab. 1;

Table 1. Comparison of land use structure of drainage basin

	Land use structure of drainage basin [%]	
	2011	2025
Built-up areas	15	55
Gardeners partnerships and recreation zones	11	11
Agricultural lands	74	34

One should note the decrease in the proportion of agricultural land from 74% to 34%, and the increase in building area from 15% to 55%. In this connection, one should emphasize the significant decrease in the number of "reclamation" channels, i.e. the channels which increase crop productivity. At the same time, one should note the increase of the number of channels that provide drainage of rain and snowmelt runoff from built-up areas, i.e. the channels of the "open drainage system of urban areas";

- the main causes of decrease of efficiency of the open drainage network is the destruction of the designed profiles of channels, growth of channel vegetation, littering of channels with fallen trees and household waste, siltation of the channel beds, destruction of structures and sedimentation pipeline-crossings;
- almost all channels (~100%) are invaded by grass and shrubs, more than half (~60%) of the channels are overgrown with trees;
- lining of trunk channels is missing or destroyed except in cottage areas where channels beds are

strengthened by geogrids, gabions, stones, etc.

The next step was to make an integral assessment of condition of channels of the open drainage network, with the following gradation:

1. “Good condition”: the channel is free from vegetation, no erosion and earth flow in slopes, no bottom erosion and silting, no backwater of the closed drainage collectors (CC), no stagnation of water along the channel’s length. Pipeline crossings are in a satisfactory condition, movement of water is not impeded, no backwater.

2. “Satisfactory condition”: the channel is in operating condition, channel opening is visible, no backwater, there are slight earth flows in slopes and siltation of bottom, overgrown shrubs and hygrophilous vegetation along the length does not exceed 30%, bottom lining is not destroyed and not silted, no stagnant water in channel. There are traces of operational activities. Pipeline crossings are in a satisfactory condition, movement of water is impeded, backwater available.

3. “Unsatisfactory condition”: the channel bed is overgrown with shrubs and hygrophilous vegetation for more than 30% along the length, opening of closed channel is not visible, there are washouts and earth flows in slopes, erosion and siltation of bottom. Movement of water is negligible or unavailable due to the high roughness. Pipeline crossings are in unsatisfactory condition, movement of water is greatly impeded, strong backwater.

4. “Very poor condition”: the channel is overgrown with shrubs, trees and hygrophilous vegetation for more than 30% along the length, erosion and destruction of slopes up to full stop of water movement. Pipeline crossings are in unsatisfactory condition, there is virtually no movement of water.

The analysis of results of the field survey showed that no channel may be assessed as in “good condition”, and 80% of the surveyed channels are rated as in “unsatisfactory condition”.

The economic assessment of the consequences of the loss of functionality of drainage systems was carried out on the basis of the calculation of the potential economic damage from the flooded areas. The assessment took into account the information on the future land use of the drainage area of each channel (the type of use of fragments and the size of the drainage). The assessment was performed for all channels and watercourses in the territories directly adjacent to St. Petersburg and under the City administrative control [22]. The calculated value of the potential loss in the aggregate with the value of the integral assessment of channels performance enabled the researchers to sequence the measures to restore the operability of channels of the “open drainage system of urban areas”. The channels, which need to take major repairs and reconstruction in the first place and in the shortest possible time, were identified as the channels with a minimum integral rating of performance (“unsatisfactory” and “very poor”) and as the channels that lost their operability which will result in the future maximum economic loss. The results of functional zoning of the adjacent territory and the assessment of the channels conditions show that 39 open drainage channels should be restored during the first stage of works, 107 channels have to be repaired within the second stage and 28 channels within the third one.

4. Conclusions

This paper presents an integrated approach to solving problems associated with the forecast of the future state and ways of development of the open drainage network on the example of St. Petersburg districts. The basis of the developed algorithms is the use of modern geographic information technologies for processing and interpretation of satellite images and topographic map-boards, spatial analysis and solutions of functional tasks of the drainage network development [23]. The developed geographic information system helped to resolve the spatial hydrological problems of the determination of optimal configuration of the surface drainage network within the development of St. Petersburg area. The works performed allowed to define the engineering activities for restoration and improvement of the surface drainage network, and consequently to prevent the flooding of St. Petersburg area.

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