Alluvial soils of the Gulf of Finland. Composition, properties, and suitability for creating green spaces

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Abstract. In Saint-Petersburg and its surroundings land reclamation works by hydraulic filling have been performed for several decades. For the hydraulic filling fine-grained slightly silted and clayed sands from the bottom of the Gulf of Finland are used. We have examined the properties of alluvial soils as substrate for planting, figured out unfavorable hydrophysical features of the soils related to soil fractionation caused by water flows while hydraulic filling, which, in their turn, have negative impact on preservation and growth of vegetation. We have given examples of measures on melioration of soils, at the same time having taken into consideration their features while the design performance and working on creation green spaces on the alluvial soils.

1. Introduction

Hydraulic deposition of soil as a method of engineer preparation of territories for urban development, or greenery expansion, or for any other purpose is widely used not only in Saint-Petersburg [1], but in many foreign countries as well [2]. Despite the certain negative impact of hydraulic filling works on aquatic ecosystem of the Gulf of Finland [3, 4], this method should be accepted as rational because it enables to prevent forest green zones and suburban agricultural lands from urbanization in case the city boundaries expand.

Saint-Petersburg is a seaside city. Nevertheless, throughout long-term historical development the city itself had been cut off from the sea by wide lowered strips of land which were prone to be flooded by slight piled-up flows, and spread into the depth of the mainland for 1-2 km. The least arranged parts of the city with inexpressive buildings are exposed to the Gulf of Finland. Excessive swampiness and predominance of poor, often peaty soils had long been a source of serious troubles on the way of the city boundaries expansion and its outlet to the sea.

The prefatorial condition of beginning the development on the coast was performance of major works aimed at banking the level of coastal lowlands up to the flood-free levels through alluviation. The mentioned above works performed in Saint-Petersburg and its surroundings were started more than 50 years ago. For hydraulic filling finely grained slightly silted sands and clayey sands from the bottom of the gulf in shallow-watered zones were used. Performance of works on reclamation of territories encouraged beginning of forming the waterfront of the city. The lower terrace of the Gulf of Finland shore has been one of the essential places for urban and green areas development for several
latest decades. In the coastal district of the city major parks are established: Yuzhno-Primorsky Park, the Park of the 300th anniversary of St. Petersburg, Primorsky Victory Park; embankments are developed; green spaces are arranged in residential areas. In view of the above, the significance of exploring the composition of alluvial soils and features of landscaping in more detail is in no doubt, regardless the publications we already have [5-10].

The goal of our research is to explore characteristics of the alluvial soils, to analyze the condition of the vegetation on reclaimed territories, and to work out measures upon their amelioration.

2. Methods and Materials
The object of the research is alluvial soils of the coastal parks of Saint-Petersburg. The beginning of reclamation of the territory was preceded by performance of preparatory works: rooting out shrubbery and underwood on the territory, dividing the coastal area into separate several tens hectares sized plots for hydraulic filling, arrangement of protection dikes, launders, water-collecting headers, jack ladders, pipeline systems. The method of alluviation of territories by means of concentrated output of burdened stream of water (end-type hydraulic filling) which is traditional in Saint-Petersburg is known as the easiest one, and it is usually applied for alluviation with uniform non-silted sands.

The technology of hydraulic filling works has a strong impact on properties of alluvial soils. When hydraulic fill of territories occurs, soils fractionate under water flows and diverge by grain size, therefore on alluviation maps there are plots of ground with different granulometric textures and characteristics of alluvial soils. Nearby outputs of burdened streams (mixture of water and fill mass) most coarse particles appear (coarse-grained sand and gravel), medium-sized grains are washed off by water streams significantly farther away from the output point, and the finest grains are washed off into so-called drain pond which develops in areas with low markings at launders. There the rate of the flow slows down, and the finest silty-colloidal grains deposit. The texture of the alluvial soils in those areas is starkly different from the granulometric textures of soils in above-water reclaimed plots (beyond the drain pond). The depth of water in those ponds can reach one and a half meters. With a change of the places of burdened streams output the granulometric texture of soils changes too, but the place of the launder and the nearby drain pond remain unchanged for the whole period of the hydraulic fill. Presence of layers of heavier sands in borrow pits, nonadherence of the prescribed amount of panning (wash-off) of fine grains, water level decrease in the gulf with the dredger in action, grabbing lower clay richer soils – all the mentioned above causes heaving of the granulometric texture.

While gathering materials and performing researches we have applied numerous methods which were used during the exploration of soils and grounds [11-13].

The granulometric texture of soils has been examined by the method of Professor Sabanin, Relative weight by All-Union State Standard; Weight by volume; Chemical Features.

3. Results and Discussion
The average-weighted diameter of sand grains decreases in size in the direction from the place of wash-off to the launder. The granulometric texture of soils (horizontal distributing of granules) depending on farness distance from the place of fill material discharge is shown in table 1. Deposit of granules by the angle of section (vertical distributing of granules by section) has been examined through the example of two different plots of the alluviation map and shown in table 2.

| Distance from the point of the burdened streams discharge, m | Granule sizes, mm     | Types of soils by granulometric texture |
|-----------------------------------------------------------|------------------------|----------------------------------------|
| 1-0.25                                                    | 0.25-0.05              | 0.05-0.01                              | <0.01                                      |
| 5                                                        | 70.7                   | 25.2                                   | 3.7                                        | 0.4  | loose sand                         |
| 25                                                       | 46.6                   | 46.5                                   | 4.1                                        | 2.8  | loose sand                         |
| 50                                                       | 28.0                   | 49.2                                   | 16.8                                       | 6.0  | cohesive sand                       |
The thickness of layers ranges from one millimeter to several centimeters, and the total thickness of the alluvial soil reaches 5-150 cm. As the depth of sampling comprises 0-5 cm, the darker organic layers and mineral layers of different granulometric texture can be distinguished. The thickness of layers can vary, and some are less than 0.5 cm. Sorting of soils with water flows by the size of granules is the most significant obstacle which doesn’t allow to create the uniform layer, and the bigger discharge and the higher flow rate of the burdened stream of water output from the end of the pipeline, the larger alluviation map is and the more significant the depression of the terrain of the reclaimed territory, the more prominent soil fractioning is.

Table 2. Granulometric texture of soils. Vertical distributing of granules.

| Place of section | Depth of sampling, cm | Granule sizes, mm | Types of soils by granulometric texture |
|------------------|-----------------------|-------------------|----------------------------------------|
| Section 1.       | 0-10                  | 1-0.25 0.25-0.05 0.05-0.01 <0.01 | loose sand                             |
| Lain 20          | 10-20                 | 75.5 20.5 3.0 1.0 | loose sand                             |
| meters away      | 20-30                 | 63.0 28.3 4.0 4.7 | loose sand                             |
| from the point of burdened streams | 50-60 | 20.2 36.8 32.6 10.5 | clayey sand                           |
| 40-50            | 54.5 28.7 10.5 6.3 | cohesive sand      |
| 60-70            | 8.7 40.8 45.4 5.1  | cohesive sand      |
| 10-80            | 7.0 41.5 50.9 0.6 | loose sand         |
| Section 2.       | 0-10                  | 0.5 10.8 52.7 36.0 | medium-textured loam                   |
| Lain 15 meters away | 10-20 | 7.5 42.7 25.5 24.3 | light loam                            |
| from the drain pond | 20-30 | 14.8 35.5 44.6 5.1 | clayey sand                           |
| 30-40            | 2.2 25.8 43.5 28.5 | light loam         |
| 40-50            | 1.2 19.5 58.3 21.0 | light loam         |
| 50-60            | 0.2 11.3 60.7 27.8 | light loam         |
| 60-70            | 0.2 26.0 53.7 20.1 | light loam         |
| 70-80            | 0.2 30.0 27.3 42.5 | heavy loam         |

Sorting of soils with water flows by the size of granules is the most significant obstacle which doesn’t allow to create the uniform layer, and the bigger discharge and the higher flow rate of the burdened stream of water output from the end of the pipeline, the larger alluviation map is and the more significant the depression of the terrain of the reclaimed territory, the more prominent soil fractioning is.

The fill material can contain vegetation and animal remains as well as organic substance (like plankton and benthos), caulds, rootstalks and seeds. On the bottom of the gulf there can be stored fossil peat deposits appeared as a result of transgression and regression of the Baltic sea waters in its historical past. That is the reason why alluvial soils contain organic particles. The presence of bigger or smaller amount of silty-colloidal mineral and organic particles gives the alluvial soils significant hydrophilicity and causing slow water loss.

Composition of alluvial soils includes the following minerals: quartz - 71-76%, potassic feldspars – 16.7-22.8; plagioclases – 3.9-5.4; biotites – 0.2-0.4, hornblended – 0.3-1.3; leptochlorites – up to 0.3; pyroxenes – 0.1; apatites – 0.1; garnets – 0.1-0.6; ores – 0.1-0.3%. Clay fraction is mostly represented as hydromicas. Presence of up to 3-4% of organic substance in alluvial soils is favorable for appearance of thixotrops and quicksand. Under substantial humidity alluvial soils can be fluid. With their several hydrophysical features freshly filled soils (finely grained clayey sands, clay loams) have a close resemblance to clays.

Soil profile (figure 1) made on the plots of the reclaimed territory display structureless grey or greyish straw-colored layer with discernible lamination. The lamination depends on the alternation of darker organic layers and mineral layers of different granulometric texture. The thickness of layers varies from one millimeter to several centimeters, and the total thickness of the alluvial soil reaches 5-
6 meters when the hydraulic filling work was done in the water area. During the laying of sections (soil pits), the alluvial soil splits into layers. Above the thickest alluvial layers gravity water can accumulate, which forms temporary water table. When sampling for humidity determination, the texture of thick layers deteriorates. Gravity water immediately leaks down. Herewith, the results of layer-by-layer determination of soil moisture are likely to get distorted. While drilling wells for measuring levels of subsoil waters, well tubing was applied, as under dynamic effects non-stabilized soils can get a viscous, ‘runny’ state.

Figure 1. Soil profiles of the alluvial soils on laid plots in different locations. (a) – Yuzhno-Primorsky Park; (b) – Primorsky Victory Park.

The most important hydrophysical properties of soils, such as compaction, permeability, water-retaining capacity, filtration, height of capillary action etc. are in no small part determined by mutual disposition and granulometric texture of soils. The soil moisture within the alluviation map is different and it varies from 0.3 percent by weight in coarse-grained sands to over 35-37% in loamy alluvial deposits. Low moisture values highlight the level insufficient for proper vegetation growth, whereas high values highlight excessive wetness. Homogeneity of soils and prevalence of fractions of a definite size are characteristic for particular areas on the alluviation map. The major part of the alluviation map territory is characterized by absence or scarceness of silty-colloidal granules which are crucially important for the development of the primary processes of soil formation and amelioration.
While hydraulic filling work, these granules accumulate in desilt basin or flow with clarified water back into the gulf, which causes muddiness of water in it [3, 4].

Prevalent in alluvial soils are fractions of fine-grained sand and coarse dust which have a very weak absorbing capacity. Strong abundance of silt particles in soils makes them poor at water permeability and prone to quick overcrust. The presence of small amount of silty organic and clayey particles increase the water-retaining capacity and slow water loss. The alluvial soils consist of elementary particles which are not in the micro-aggregate state.

The specific weight of the solid phase of the alluvial soils (determined by pycnometer) varies from 2.66 to 2.70 gr/cm³ and depends on the structure of minerals included in sampling and on presence of organic impurities. There are no consistent patterns observed in specific weight distribution down the profile (vertical section) of the alluvial soil. The weight by volume (determined with a cutting ring) ranges within 1.42 to 1.65 gr/cm³. The porosity of the alluvial soils varies from 38.2 to 47.4%. Hydraulic filling is firmer, compared with dry filling work. The coefficient of alluvial soils filtration (according to the data acquired through observation of geodetic engineering works and surveys in the net of enterprises) for samples with disturbed texture from different areas of the alluviation map ranges from 0.04-0.58 to 1.93-2.73 m/d. The field survey has shown us that these values are overstated for the drain pond area, as the foliation of soils was not taken into consideration.

Non-uniformity and foliation of soils contribute to the increase of the total value of the agrarian moisture-retention capacity of the section. In foliated soils occasional menisci on junctions of layers cause ‘stair-stepping’ increase of moisture. Soils with discernible foliated structure are marked by interlayer horizontal filtration which in some plots (near the former drain pond, in particular) can be in large excess over the vertical filtration. Its presence causes extra moisture, however, due to deposits of large amounts of floury, clayey and silty particles and discernible foliation, vertical filtration of water is obstructed. In the area of the former drain pond soil stratum can be completely saturated with water which may emerge on the surface and is likely to cause swamping. This is the factor in the degradation of lawns on certain areas of parks. The filtration may also be difficult due to the close level of subsoil waters which, as a consequence of the backwater effect by the Gulf of Finland, rivers and channels, have got almost no outlets. The level of subsoil waters on reclaimed territories is predominately situated at depths down to 1.5-3.5 m. The distance from the coast of the gulf have influence on the oscillatory amplitude of the water level. The farther the distance is, the more significant changes of subsoil waters level during the growing season are.

The chemical properties of the subsoil waters are characterized by irregularly changeable values by the soil profile (vertical section). The pH ranges from weakly acidic to weakly alkaline, and its values are favorable for growth of vegetation. The values of the hydrolytic acidity range within 0.3-0.8 mg-equiv. per 100 gr., the degree of saturation with alkali comprises 94-98%. The amount of the essential nourishment components in soils is poor and insufficient for healthy growth of plants. Small amounts of nourishment components are associated with deposits of silty organic particles. There are no consistent patterns observed in classification of chemical values by sections of alluvial soils, as opposed to natural soils. The alluvial soils classified by amounts of salts - chloride ions and sulfate ion – are considered non-saline or slightly saline. It is associated with shallow waters in the coastal part of Gulf of Finland and large amount of sweet water brought by the Neva River and other rivers flowing into the gulf. Insignificant amount of salts is relatively quickly washed away under conditions of water cleansing regime which is conventional for Saint-Petersburg.

The practical experience of creating green spaces of the reclaimed territories has shown that alluvial soils are complicated and not quite favorable substrate for vegetation, such as trees, shrubbery, or perennial plants. The high percentage of loss (death) of the trees and shrubbery planted in Yuzhno-Primorsky Park, Park of the 300th anniversary of St. Petersburg and on other plots of the reclaimed territory, degradation of lawns on separate areas of the parks indicate complicated soil conditions. They are associated with significant density of alluvial soils packing, poor sources of nutrients, and unfavorable hydrophysical values. Properties of alluvial soils are unfavorable for vegetation growth and require more thorough preparation of the soil, to apply larger amounts of the topsoil when creating
green spaces. It is necessary to take into consideration properties and particularities of the alluvial soils when designing a green space.

Park construction on alluvial soils was performed with the use of imported topsoil. The thickness of the fertile layer of soil comprised 15-20 cm under lawns, trees were planted with soil held by a rootball. Planting holes were up from 1 to 1.7 m in diameter.

The main reason of vegetation loss and lawns bad condition is, in our opinion, failure to take into scrupulous consideration the specific features of alluvial soils at all the stages of work, beginning from designing green spaces on the reclaimed territories, planting and maintaining vegetation. Parks design and construction were performed the same way as designing green spaces on natural soils, whereas green spaces on the alluvial soils created by hydraulic filling require taking into account such specific features as foliation, density, and peculiarities of the hydrological regime.

The researches we have repeatedly carried out on plantations in the Yuzhno-Primorsky Park have shown non-satisfactory plant growth in several areas, as well as loss of trees. Death of trees is observed in different periods of growth — 5 -10 or more years later after planting. Digging roots of dead trees has shown that their root systems do not always grow beyond their planting holes. At times it happens that the roots twist against the walls of planting holes, failing to penetrate into alluvial soil of firm consistency. Over the course of time an unbalance between overgrown tree crown and insufficient mass of roots in a planting holes occurs. As far as we can see, it is the main reason for loss of trees. Among the dead trees, lindens comprise the biggest number, as this tree species is known to be the neediest of soil fruitfulness. Attempts of planting new trees to substitute the dead ones do not always give satisfactory results. Even if the new vegetation gets accustomed and grows well at the early period right after planting, in after years deterioration of ornamental qualities of trees is again observed, and gradually tree crowns wilt.

At early-spring and autumn periods, and at times of showers in summer on areas of the former drain pond there has been observed longstanding moisture which causes lawn degradation. Performance of drainage works and drainage system installation in the Yuzhno-Primorsky Park has had quite a weak positive impact on growth of plants, as hydrological particularities of reclaimed territories were not sufficiently taken into consideration.

Without radical improvement of the alluvial soils it is impossible to find a comprehensive solution of vegetation growth problems. Particular areas require a more expensive and of a higher quality preparation of the soils for plantation, including excavation of unfavorable patches of earth and substitution them with imported topsoil.

Methods of preparation of alluvial soils must take into account the function of the green space, its size, the possibility of mechanized preparation of the substrate, and how soon commissioning of the green space is possible. With a further term of commissioning the preparation of the soil can take more time and be less labour-intensive. To surge permeability of soil, to eliminate its foliation and increase the rate of gravity water flowing on the reclaimed areas during the construction of parks, it is necessary to operate the ground with a subsoil plough. When designing and installing a drainage network, it is worthwhile to consider the direction of the water flow towards the former drain pond. Designing artificial waterbodies on places of drain ponds with extraction of floury and silty-colloidal granules of soil and their transportation to areas with coarse-grained sands will help to improve the hydrophysical values of soils on those territories. Excavation of hardly-filtrating soils on particular areas near lauders and packing those pits with drainable soils can also improve the hydrological regime of the territory. In places of heavier mineral soils deposits it is worthwhile to expand the planting pit.

For structure creation and increasing the accumulation of organic substances in the long-term planning of creating parks, it is meaningful to plant legume-grass mixture for 3-5 years with annual plowing of grass mixture at the stage of the richest harvest. This method of green manuring may increase supplies of organic substances in soil. While creating intradistrict green spaces it is necessary to use artificial soil mixtures.
The natural conditions of the coastal area along with peculiarities of alluvial soils as such are characterized by more frequent and stronger winds from Gulf of Finland. The selection of tree and shrubbery species should be put into practice with consideration of ecological conditions of the coast. When creating green areas on alluvial soils it is necessary to take into account their specific features and to apply a system of meliorative measures which will help to eliminate negative values.

4. Conclusion

Alluvial soils within the alluviation map are characterized by various granulometric textures in vertical section (foliation) as well as in plan view (gradual heaving of soils in the direction from the place of fill material discharge to the drain ponds).

The specific features of alluvial soils are their high density, sharp decrease of filtration capability on the areas of former drain pond due to their foliated structure, and deposits of significant amount of floury, clayey and silty particles. On such plots interlayer underground horizontal filtration of water is observed.

In places of coarse-grained sands deposits (including pebble stones) soils have high filtration values. On those areas plants undergo lack of water.

When designing parks on the reclaimed by hydraulic filling areas it is worth to take into account the locations of drain ponds. Measures on development of alluvial soils for creating green areas should be based on consideration of particularities of soils on every separate plot, selection of tree and shrubbery species, and sufficient preparation of the soil.

Taking into consideration of the features of alluvial soils when designing and creating green areas and maintaining the vegetation is the necessary condition which will encourage resilience, decorative value and proper growth of the vegetation on the alluvial soils.

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