Monitoring of flooding of rice irrigation systems via laser scanning and digital imaging

A A Solodunov¹, M A Bandurin² and S K Pshidatok¹

¹Kuban State Agrarian University named after I T Trubilin, 13, Kalinina Street, Krasnodar, 350044, Russia
²Platov State Polytechnic University (NPI), 132, Prosveshcheniya Street, Novocherkassk, 346428, Russia

E-mail: 2602555@mail.ru

Abstract. The paper presents the study of various technologies to monitor flooding of rice irrigation systems and hydraulic engineering structures as such. It considers planning and prospects of improvement through the introduction of modern systems of laser scanning and digital imaging. It also analyzes the condition of planning works on rice fields in Lower Kuban. This year it is planned to sow 134.5 thousand hectares of rice this year in Krasnodar Krai, which is nearly 8 thousand more than last year. The region produces 87% of rice in Russia. Rice irrigation systems within the rice cultivation region cover huge territories with different agrometeorological and hydro-reclamation conditions. The cultivation of this culture is critical in relation to humidity of top soil, its temperature and surface microlief. Rice industry in Krasnodar Krai is still reviving. Today the productivity of this culture in Russia makes about 200 thousand tons of grain annually. This is quite sufficient to satisfy the domestic needs of the country. Russia even has an opportunity to import about 50 thousand tons of grain annually. The total length of flood embankment from the Krasnodar reservoir to the mouths of the Kuban and the Protoka rivers is 650 km. Since 1998 and till present, the flood embankment systems were examined several times to detect sites in unsatisfactory technical condition threatening the emergency burst. Technical condition of the flood embankment system of the Kuban and the Protoka rivers is considered emergency. The design of rice irrigation systems is based on the modular principle satisfying the integrated approach to internal network. It is recommended to introduce the new way of planning thus ensuring the maximum approximation of surfaces of rice fields to a horizontal surface.

1. Introduction

Rice has been grown in Krasnodar Krai since the 1920s of the last century, large areas of rushy floodlands were drained. It was also decided to use these wet lands for rice growing. The area of the first experimental rice plot was more than 50 hectares. A new exclusive method of rice cultivation created by domestic landowners was constantly improved in the next years. Initially the harvest of this culture in Krasnodar Krai made only 21-22 centners per hectare [1]. This year it is planned to sow 134.5 thousand hectares of rice this year in Krasnodar Krai, which is nearly 8 thousand more than last year. The region produces 87% of rice in Russia. Today the rice industry of Krasnodar Krai is reviving. In 2014 the rice lands have already made about 167 thousand hectares [2].

Thus far rice industry of the region is experiencing some difficulties. So, for example, until 2016 there was not a single new rice irrigation system in the region. Old rice irrigation systems used within
the region of rice cultivation cover huge territories with different agrometeorological and hydro-reclamation conditions [3]. The cultivation of this culture is critical in relation to humidity of top soil, its temperature and surface microrelief of rice fields.

Rice industry in Krasnodar Krai is still reviving. Today the productivity of this culture in Russia makes about 200 thousand tons of grain annually [4]. This is quite sufficient to satisfy the domestic needs of the country. Russia even has an opportunity to import about 50 thousand tons of grain annually [5].

The landscape of modern delta of the Kuban River is located on both coasts of the river and stretches to the north up to the Kirpilsky Estuary [6]. In the west and the east it borders with the landscape of Azov accumulative alluvial-marine low-inclined plain (mouth of the Protoka River) and the landscape of Azovo-Kubansky highland of accumulative-erosive undulating flatlands respectively. In the south its conditional border are the Adagum River and Dry Aushedz, Varnavinsky, Kryukovsky and Shapsug reservoirs [7]. The development of rice growing on its area is a typical agricultural phenomenon of a landscape. Almost the whole territory represents rice checks limited by irrigation and discharge channels [8].

The first rice irrigation system Tikhovskaya was built in 1931 in the Lower Kuban on the area of 1.1 thousand hectares. By 1941 there were 10 thousand hectares of irrigation systems on boggy and salted lands, and by 1965 – 70 thousand hectares [9]. In May, 1973 the largest Krasnodar reservoir in the North Caucasus was put into operation on the Kuban River [10]. The Complex Scheme of Use and Protection of Water Resources of the Kuban Basin ensuring further increase of irrigated areas to 550 thousand hectares, including the areas of rice irrigation systems – to 255 thousand hectares, was developed and approved the same year in Krasnodar Krai. The Tshchiksky reservoir was built in 1941 on the river Belaya in Krasnogvardeisky district [11]. The Shapsugsky reservoir was built in 1952 on the river Afips in Oktyabrsky district of Adygea. Over this period the region managed to create a unique antiflood system that included Krasnodarskoye, Shapsugskoye, Kryukovsky, Varnavinsky reservoirs with a total detention basin of 918 million m³; 650 km of flood embankment of the Kuban and Protoka rivers; Fedorovsky hydraulic power system with discharge outlet of the Kuban River to Kubanskaya, Maryano-Cheburgol'skaya, Ponuro-Kilininskaya and Fedorovskaya rice systems with a flowrate of up to 250 m³/s [12].

Slightly over half a century 415.3 thousand hectares of reclaimed lands, including 390.8 thousand hectares of irrigated and 24.5 thousand hectares drained lands were put into operation in Krasnodar Krai [13]. The structure of irrigated lands of Krasnodar Krai includes 60.1% or 235 thousand hectares of rice irrigation engineering systems [14].

The total length of flood embankment from the Krasnodar reservoir to mouths of the Kuban and the protoka rivers is 650 km. Since 1998 and till present, the flood embankment systems were examined several times to detect sites in unsatisfactory technical condition threatening the emergency burst [15]. Besides, some sites were exposed to topographic-hydrographic studies.

The antiflood system of the Lower Kuban basin changes its properties over time, for example, the stability of dams of ridging is different in control stations during and after flood. The technical condition of antiflood system elements is usually assessed during low water season, which does not give realistic estimates on safety conditions. In most cases the conclusions are based on visual observations and limited instrumental measurements [16].

On certain sites water protective shafts are so close from edges or already form an edge that from destruction they are only temporary protected to ensure bank strengthening. Earlier on such sites the passby shafts were built and later there were about 2-3 lines, and the process of destruction continues. There is simply no place to build new shafts. Besides this requires huge investments and will bring only temporary effect.

In recent years the increasing attention is paid to regulatory actions [17]. Modern protective and regulatory structures on the rivers do not imply their cardinal transformation. The general condition shall be the strive towards minimum violation of morphology of courses and floodplains, which may be found in the zone of intensive washouts. The reaction of a river flow to earthworks performed in its course
depends on the fact whether the artificial change of channel forms corresponds to channel trends on this section of the river. In cases of alignment of alluvial bends or clearing of channels such compliance is valid and the flow “supports” these actions, i.e. contributes to the development of a course in desirable direction. In fact these actions will only accelerate the course of events, which even without them, but later, would happen naturally [18].

The regions of river regulation systems of the Kuban and the Protoka rivers belong to zones with seismicity of 7-8 points. The maximum flood discharge is taken as 3% of availability and testing – 0.5%, which in the conditions of overregulation Krasnodarsky, Varnavinsky, Kryukovsky and Shapsugskky reservoirs are identical and equal to 1500 m$^3$/s on the section of the Kuban River from Krasnodar reservoir to Tikhovsky hydraulic power system and 650 m$^3$/s – along the Kuban and the Protoka rivers below Tikhovsky hydraulic power system. The excess of edge of dam over the settlement water horizon is taken as 1.2 m [19].

Technical condition of the flood embankment system of the Kuban and the Protoka rivers is considered emergency. Over a long period of operation it suffered considerable damage and changes of the main hydraulic engineering structure of the embankment system [20]:

- dams are washed away and structurally weakened, slopes are deformed in many sites;
- edge of dams are collapsed by 30-50 cm and deformed in certain sites;
- flood embankment body is collapsed in some places;
- accumulation of alluviation in the course on certain sites led to sharp reduction of flow section of a water flow with simultaneous increase of erosive processes;
- there are sites with offshore motion of sediments where soil collapses entraining flood embankment sites. This is most often observed on concave meander sites.

Further operation of the antiflood embankment system in such state may lead to negative consequences in case of huge floods:

- dam failure and flooding of adjacent territories;
- destruction of coast and developed sites.

2. Materials and methods

In recent years the increasing attention is paid to the study of various technologies to monitor the flooding of lands of rice irrigation systems. The problem of operation is particularly relevance since on certain sites the water protective shafts of rice irrigation systems are so close from edges or already form an edge that from destruction they are only temporary protected to ensure bank strengthening. Earlier on such sites the passby shafts were built and later there were about 2-3 lines, and the process of destruction continues. There is simply no place to build new shafts. Besides this requires huge investments and will bring only temporary effect [21].

Besides, modern protective and regulatory structures on the rivers do not imply their cardinal transformation. The general condition shall be the strive towards minimum violation of morphology of courses and floodplains, which may be found in the zone of intensive washouts. The reaction of a river flow to earthworks performed in its course depends on the fact whether the artificial change of channel forms corresponds to channel trends on this section of the river. In cases of alignment of alluvial bends or clearing of channels such compliance is valid and the flow “supports” these actions, i.e. contributes to the development of a course in desirable direction. In fact these actions will only accelerate the course of events, which even without them, but later, would happen naturally. In fact these actions will only accelerate the course of events, which even without them, but later, would happen naturally. The degree of reliability and durability of the embankment system – III. The regions of arrangement of the embankment system of the Kuban and Protoka rivers belong to zones with seismicity of 7-8 points. The maximum flood discharge is taken as 3% of availability and testing – 0.5%, which in the conditions of overregulation Krasnodarsky, Varnavinsky, Kryukovsky and Shapsugskky reservoirs are identical and equal to 1500 m$^3$/s on the section of the Kuban River from Krasnodar reservoir to Tikhovsky hydraulic power system and 650 m$^3$/s – along the Kuban and the Protoka rivers below Tikhovsky hydraulic power system. The excess of edge of dam over the settlement water horizon is taken as 1.2 m.
The late nineties were characterized by new achievements in obtaining highly detailed map materials (scale 1:5000 and more). It was generally caused by new methods of the Earth’s remote sensing using pulse lasers. Instead of classical aerial photography the consumers of mapping information were offered high-precision laser and location shooting combined with digital imaging. Aerial laser scanning represents the “photo+laser” combination since laser shooting without aerial photography is rarely applied [22]. Gradual distribution of this method in the world and progress in the field of digital cameras and laser scanners evolved the accuracy and detail of obtained data – from 1:5000 in the late nineties up to 1:500 by the beginning of 2015.

Laser scanning is a variety of active shooting. The semiconductor laser installed on aviacarrier (a plane, a helicopter) (working in the pulse mode) performs discrete scanning of the Earth’s surface and objects located on it thus registering the direction of a laser beam and beam transmission time. Aerial laser scanning combined with aerial photography is currently the most effective technology of high-precision models of the area. The use of aerial laser scanning allows creating contour, geodetic plans and maps of all succeeding scales in the shortest time possible [23].

The principle of aerial monitoring of flooding lands of rice irrigation systems is as follows: during flight the onboard detector of an aircraft detects flight trajectory coordinates, the inertial navigation system fixes equipment tilt angles, the air laser scanner acts as a range finder fixing a angle and distance from aircraft equipment to the underlying surface. To specify the spatial position of the aerial laser scanner the network of surface base stations is created during flight, which defines the differential correction for the navigation system of aerial shooting equipment. The aerial imaging gives the pixel array of aerial laser scanning, where each pixel has spatial coordinates XYZ in the necessary system of coordinates and a set of aerial images with parameters of their external orientation. Such data set allows immediately creating color high resolution orthophotomaps. The processing of obtained aerial shooting data and cartographic maps are the final stages of aerial scanning and imaging (Figure 1).

![Figure 1. TIN 1: (a) built according to unprocesses point cloud received via aerial scanner; (b) built according to reflection pulse energy received via aerial scanner.](image)

The distinctive feature of aerial scanning and digital imaging for monitoring of flooding within rice irrigation systems is high execution speed, especially in the conditions of remote areas and areas with dense wood and shrubby vegetation. The aircrafts under command or unmanned aerial vehicles are used as the carrier for the aerial scanner.

The aerial laser scanner is based on the pulse principle. This impulse, except space point location,
gives the energy of the reflection pulse – intensity of reflection. Such set of points is called the point cloud. But these points are not suitable for work, it is necessary to perform their preliminary processing, i.e. division into points of detail and points outside the Earth.

The entrance control of source data of laser scanning and aerial imaging for monitoring of floods of lands of rice irrigation systems is carried out through validation of the following data:
- degree of coverage of sheets with shooting data; compliance to requirements of planned and high-rise fixed points in relation to laser reflection point in the system of coordinates and heights of an object;
- availability and correctness of laser reflection points of data on sequence and intensity of laser impulse reflections and the number of aerial survey route;
- convergence of laser reflection points from different flights on height (not more than the laser error);
- convergence of laser reflection points in relation to previous data in case of rerouting and additional shooting (not more than the laser error);
- compliance with program requirements concerning spatial resolution of aerial images;
- correctness of calibration of camera file(s) and elements of external orientation;
- compliance with program requirements concerning density of the land surface coverage (Figure 2).

![Figure 2. TIN 1: (a) built according to unprocessed laser point cloud received via aerial scanner; (b) built according to point cloud with identification of objects received via aerial scanner.](image)

To build orthophotomaps we need points of laser reflection and land surface, otherwise the image will be distorted (high-rise objects, for example buildings, or wrong points were part of the earth), which will give the wrong idea on the location of objects in the area. Therefore, before processing data on aerial photography we have to make sure of quality and accuracy of received classification for its further use [24].

For example, after some years of operation of the Azov rice irrigation system irrespective of the quality of capital planning there is a need for operational planning, at the same time the specific volume of earthwork makes 250-300 m³/hectare, the size of cuts – 10-15 cm. The analysis of various ways of planning showed that in construction and operation of rice fields it is necessary to ensure continuous geodetic control since the scrapermen use data of intermediate leveling of a field.

Planning is usually proceeded by vertical shooting of a surface of rice fields with the project of planning works to perform flooding monitoring of lands of rice irrigation systems. The design mark of a rice field provides balance of earthwork and gives the chance to install the working equipment at the design height. Vertical shooting of a field is made by squares, by alignments every 20 m of parallel
steps. Precise positioning of the aviacarrier on a field may be reached by the installation of equipment that excludes labor-consuming preparation of alignments, automates traffic control and increases productivity of works.

The study showed that significant improvement of planning quality in construction and repair of rice fields can be reached with laser control systems. Laser control makes it possible to obtain information on roughnesses and defects on a regular basis. It gives a chance to observe planning accuracy with the required specification tolerance. The introduction of laser systems allows increasing productivity and efficiency of not only construction machines, but also specialized geodetic services, which provide a scope of work to mechanized crews and control the construction process. The design of planning works when using these optical systems of shooting is carried out manually, and when an autolevel on the personal computer is used – by means of various software. As a result of data processing we get planning schemes of fields in the form of cartograms of a microrelief and the scheme of soil transportation. Computer design gives exact balance of earthwork, forecasts productivity of rice and consumption of water according to a relief, as well as an optimal transport solution displaying the scheme of soil transportation and determination of distances.

3. Conclusion
Due to decreased reliability of structures within Krasnodar reservoir, growth of seismicity, rare availability, the water level at the lower limit was reduced by 0.9 m, which reduced its importance in the system of antiflood protection of the Lower Kuban. The Shapsugskoye reservoir as not satisfying safety conditions and is completely drained. Hence, flood waters of the left-bank mountain rivers with a flowrate of up to 360 m³/s directly get to the Lower Kuban thus affecting the reliability of the antiflood system.

The technical condition of Kryukovsky reservoir is rated as emergency, Varnavinsky – as pre-emergency. Safety level – low. The technical condition of flood embankment of the Kuban and the Protoka rivers is estimated as pre-emergency.

The design of rice irrigation systems is based on the modular principle satisfying the integrated approach to internal network.

It is recommended to introduce the new way of planning thus ensuring the maximum approximation of surfaces of rice fields to a horizontal surface. Aerial photography is suggested to define the scope of works during operational planning of rice fields and quality control. It is advisable to assess the quality of planning according to deficiency. The structures of internal irrigation systems applied in various zones of rice growing have various elements (fields, maps, irrigation and discharge channels), their hydraulic facilities are different, performed from non-uniform precast concrete units. This leads to difficulties of design, construction, organization of optimum water use and automation of water regulation of rice systems.

References
[1] Olgarenko V I, Olgarenko I V, Selyukov V I 2012 Computer technology of planning water use in irrigation systems Bulletin of the Russian Academy of Agricultural Sciences 4 12-15
[2] Bandurin M A, Yurchenko I F, Volosukhin V A, Vanzha V V, Volosukhin Ya V 2018 Ecological and economic efficiency of diagnostics of technical condition of water supply facilities of irrigation systems J. Ecology and Industry of Russia 22(7) 66-71
[3] Shchedrin V N, Vasiliev S M, Slabunov V V 2013 The basic rules and regulations for the operation of reclamation systems and structures, water accounting and production operations: monograph Novocherkassk: Helikon 657
[4] Abdrazaakov F K, Ryzhko N F, Ryzhko S N, Horin S A, Botov S V 2018 Electricity consumption decrease at pump stations during watering by multi-support sprinkling units Journal of Fundamental and Applied Sciences 10 1464-1481
[5] Degtyareva O, Degtyarev G, Togo I, Terleev V, Nikonorov A, Volkova Yu 2016 Analysis of stress-strain state rainfall runoff control system – buttress dam Proced. Eng. 165 1619–1628
[6] Matetskaya A V, Takhtamyshev V G, Bandurin A P, Lyubetsky N P, Sharkov I G, Tomilina L B, Samygin S I 2018 Social functions of orthodoxy in the context of the formation and development of collective identity and civil society in modern Russia Modern J. of Language Teaching Methods 8(6) 317–326

[7] Bandurin A P, Bandurina I P 2018 Volunteer movement’s social regulation in public space of modern youth The European Proc. of Social & Behavioural Sci. 14 106–112

[8] Abdrazakov F K, Orlova S S, Pankova T A, Mirkina E N, Mikheeva O V 2018 Risk assessment and the prediction of breakthrough wave during a dam accident J. of Interdisciplinary Res. 8(1) 154–161

[9] Bandurin M A, Volosukhin V A, Mikheev A V, Volosukhin Y V, Vanzha V V 2018 Finite-element simulation of possible natural disasters on landslide dams with changes in climate and seismic conditions taken into account J. of Physics: Conf. Ser. 1015(4) 042061

[10] Volosukhin V A, Bandurin M A, Vanzha V V, Mikheev A V, Volosukhin Y V 2018 Numerical analysis of static strength for different damages of hydraulic structures when changing stressed and strained state J. of Physics: Conf. Ser. 1015(4) 042061

[11] Ryzhko N F, Abdrazakov F K, Ryzhko S N, Botov S V 2018 The increase of qualitative indicators during watering with multiple support sprinklers J. of Fundamental and Applied Sci. 10(6) 1482–1497

[12] Yurchenko I F 2018 Information support system designed for technical operation planning of reclamative facilities J. Theoretical and Applied Information Technol. 96 1253–1265

[13] Kireicheva L V 2017 Scientific foundations of creation and management of reclamation systems in Russia (Moscow: FGBNU VNII agrokhimii) p. 296

[14] Yurchenko I F 2017 Automatization of water distribution control for irrigation Int. J. of Adv. and Appl. Sci. 4(2) 72–77

[15] Kireicheva L V 2010 New technologies of designing, substantiation of construction, operation and management of land reclamation systems (Moscow: VNIIA) p. 240

[16] Yurchenko I F 2016 Water-saving technology for planning of technical operation of reclamation systems Water economy of Russia: problems, technologies, management 5 76–88

[17] Yurchenko I F 2017 Methodological bases of creation of the information management system water use on irrigation Messenger of the Russian agricultural 13 17

[18] Degtyareva O G, Dac'o D A, Degtyarev G V, Gumbarov A D 2017 Design in cae system of low-head weir tiled foundation sinking Proc. of the Kuban State Agrarian Univ. 64 221–226

[19] Yurchenko I F, Trunin V V 2013 Methodology of creation of information technologies for operational management of water distribution at inter-farm irrigation systems Environmental Eng. 4 10–14

[20] Yurchenko I F, Nosov A K 2015 Normative and legal base of safety of hydrotechnical structures Scientific J. of the Russian Res. Institute of Problems of Land Reclamation 4(20) 262–277

[21] Kruzhilin I P, Ganiev M A, Melikhov V V, Rodin K A, Dubenok N N, Ovchinnikov A S, Fomin S D, Abdou N M 2017 Mode of rice drip irrigation ARPN J. of Eng. and Appl. Sci. 12(24) 7118–7123

[22] Kozlov D V 2001 A linear dynamic model for calculating the transverse oscillation of free-floating ice cover Water Resources 28(2) 215–219

[23] Chesnokov B P, Naumova O V, Strelnikov V A, Abdrazakov F K, Tronin B A 2016 Polyethylene production from granules using high voltage Int. J. of Applied Eng. Res. 11 2140–2144

[24] Kozlov D V, Nasonov A N, Zhogin I M, Tsvetkov I V 2017 Multifractal principles of aquatic ecosystem development control by algacenosis correction Water Resources 44(2) 259–266