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3D JAKO INSTRUMENT MONITOROWANIA OBIEKTÓW WODNYCH

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Streszczenie. Dany artykuł dotyczy problemu monitorowania obiektów wodnych w miastach. Informacje o faktycznym stanie obiektów wodnych są potrzebne do podejmowania decyzji zarządczych na ich temat. Podniesienie jakości monitorowania wykorzystania obiektów wodnych jest szczególnie ważne na obszarach miejskich, gdzie jest intensywne użytkowanie wielofunkcyjne i oddziaływania antropogeniczne prowadzą do pogorszenia ich stanu. Jednym z głównych problemów monitorowania obiektów wodnych jest brak uogólnionego systemu informacyjnego zarówno na Ukrainie, jak i poza jej granicami. Na tym tle przeanalizowany jest stan monitoringu obiektów wodnych na Ukrainie, a także doświadczenia zagraniczne w tej dziedzinie. Stwierdzono, że trójwymiarowy kataster jest narzędziem do właściwego monitorowania potrzeb informacyjnych związanych z monitorowaniem i rozwiązywaniem problemów między dyscyplinarnych zadań z zarządzania obiektami wodnymi.

Określono zbiór międzynarodowych standardów, wyznaczających podstawowe wymagania dotyczące nowoczesnych systemów katastralnych ogólnie oraz do systemów monitorowania obiektów wodnych w szczególności. Umożliwiło to stworzenie struktury warstw informacyjnych 3D-katastru obiektów wodnych. Cały zbiór informacji o obiektach wodnych jest połączony w dwóch szerokich grupach: immanentnej i transcendentalnej informacji. Główne cechy tych grup informacyjnych zostały usystematyzowane, co pozwala na odpowiednie i skuteczne monitorowanie obiektów wodnych. Proponowany jest konceptualny UML-model 3D-katastru obiektów wodnych , oparty na strukturyzacji informacji wychodzącej. Uzyskany wynik obliczenia wydajności opracowanego modelu wykazał, że w ciągu siódmego roku 3D-kataster obiektów wodnych staje się samowystarczalny, zgodnie z wymogami INSPIRE. Opracowany konceptualny model 3D-katastru obiektów wodnych zapewnia podniesienie efektywności w podejmowaniu decyzji dotyczących korzystania z obiektów wodnych.

Słowa kluczowe: 3D-kataster, obiekt wodny, model konceptualny, informacja immanentna, informacja transcendentalna, warstwa informacyjna, zestaw danych geoprzestrzennych.

3D CADASTRE AS THE INSTRUMENT OF WATER OBJECTS MONITORING

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Abstract. The article deals with the problem of water objects monitoring in urban areas. The information about an actual state of water bodies is necessary for making managerial decisions regarding them. Improving the control and monitoring of water objects is particularly important for urban areas, where intensive multipurpose use and anthropogenic impact consequently leads to damage to the water bodies. One of the main problems of water objects monitoring is the absence of an aggregated information system, both in Ukraine and abroad. Considering this, the state of water objects monitoring in Ukraine, as well as foreign experience in this sphere is analyzed. The conclusion is drawn that a three-dimensional cadastre is a suitable tool for the proper provision of information needs for monitoring and resolution of interdisciplinary water management tasks.

The set of international standards, which determine requirements for modern cadastral systems in general, and to the monitoring systems of the water objects in particular, was defined. This allowed to form a structure of information layers for 3D cadastre of water objects. The entire array of information about water objects is united into two large groups: immanent and transcendental information. The main characteristics of these information groups, which allow to carry out an adequate and effective monitoring of water bodies, are systematized. The conceptual UML-model for 3D cadastre of water objects is based on structuration of the initial information. The obtained result of calculation an effectiveness of the developed model proved that during the seventh year the 3D cadastral system becomes self-sustaining, in accordance with the requirements of INSPIRE. The developed conceptual model of the 3D cadastre of water objects provides an increasing the efficiency of decision-making on the use of water objects.

Keywords: 3D cadastre, water object, conceptual model, immanent information, transcendental information, information layer, geographic data sets.

3D ЯК ІНСТРУМЕНТ МОНІТОРИНГУ ВОДНИХ ОБ'ЄКТІВ

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Анотація. У статті розглянуто проблему моніторингу водних об'єктів у містах. Інформація про фактичний стан водних об'єктів необхідна для прийняття управлінських рішень щодо них. Поліпшення моніторингу використання водних об'єктів є особливо важливим для міських територій, де інтенсивне багатоцільове використання та антропогенний вплив призводять до псування їх стану. Однією з головних проблем моніторингу водних об'єктів є відсутність узагальненої інформаційної системи як в Україні, так і за її межами. Враховуючи це, проаналізовано стан моніторингу водних об'єктів в Україні, а також зарубіжний досвід у цій галузі. Зроблено висновок, що інструментом для належного забезпечення інформаційних потреб моніторингу і вирішення міждисциплінарних задач управління водними об'єктами є тривимірний кадастр.

Окреслено коло міжнародних стандартів, що визначають вимоги до сучасних кадастрових систем загалом та до систем моніторингу водних об'єктів зокрема. Це дозволило сформувати структуру інформаційних шарів 3D-кадастру водних об'єктів. Весь масив інформації про водні об'єкти об'єднаний у дві великі групи: іманентна та трансцендентна інформація. Систематизовано основні характеристики цих інформаційних груп, які дозволяють проводити адекватний та ефективний моніторинг водних об'єктів. Запропоновано концептуальну UML-модель 3D-кадастру водних об'єктів, що базується на структуруванні вихідної інформації. Отриманий результат розрахунку ефективності розробленої моделі довів, що протягом сьомого року 3D-кадастр водних об'єктів стає самоокупним, відповідно до вимог INSPIRE. Розроблена концептуальна модель 3D-кадастру водних об'єктів забезпечує підвищення ефективності прийняття рішень щодо використання водних об'єктів.

Ключові слова: 3D-кадастр, водний об'єкт, концептуальна модель, іманентна інформація, трансцендентна інформація, інформаційний шар, набір геопросторових даних.

Introduction. In modern cities, with high density of population and extreme concentration of social, industrial and other objects, intensive multipurpose use and anthropogenic impact consequently leads to damage to the water bodies. This causes the deterioration of the sanitary and hygienic conditions of the urban environment. In view of this, the issue of improving control and monitoring of urban water objects is particularly important. At the same time, the specifics of water bodies analyzed in research demonstrates there features that can only be modelled in three-dimensional information systems. Although nowadays in majority of countries water objects are recorded in two-dimensional systems, which leads to inadequate information about them. The full extent of necessary information for the effective monitoring of water bodies cannot be obtained in two-dimensional cadastral systems, since water objects are three-dimensional. Consequently, the features of three-dimensional information about water objects have to be determined. Three-dimensional information is usually defined as representation of spatial information about objects of the real world in the form of volumes (i.e. a mathematical model that is as close as possible to reality). This method of presenting information conveys all the properties of water objects in view of their nature. That is why a three-dimensional cadastre is a suitable tool for the proper provision of information needs for monitoring and resolution of interdisciplinary water management tasks.

Today, the information about water objects in Ukraine is fragmentarily contained in five different information systems, like Land information system (according to the Law «About the State land cadastre», Art. 1), Water information system (The Water Code of Ukraine, Chapter 6) and so on. According to The Water Code of Ukraine Water, information system in Ukraine is legally defined as the State water cadastre and includes three separate sections «Water Use», «Surface Waters» and «Underground Water». These section are maintained by three different authorities. It causes more problematic management of water objects due to these authorities use different methods of monitoring, databases and tools. Consequently, the data received by different departments is not interconnected and a unified database for monitoring cannot be obtained. The result is the lack of an information environment for decision-making on water objects (Petrakovska, Dubnytska, 2018, 33).

At the same time, foreign experience demonstrates positive examples of use the three-dimensional geoinformation systems for accounting and monitoring of water objects. Thus, the United States and Germany use a full complex of 3D GIS-tools for their water objects management (such as StreamStats in USA or Geoportal in Germany), as well as Armenia use such tools for some tasks (Narimanyan, 2011). Albania is developing 3D water cadastre since 2017 thanks to World Bank funding. It should be noted that three last countries have successfully attracted international funding sources and technical support for developing their water cadasters.

Since the basin principle of management is recognized as the most effective method for managing water bodies, information about them should be integrated into the international community. To meet this requirement, the modern, effective three-dimensional geoinformation systems of the water cadastre have to be based on the principles of INSPIRE, ISO and OGC standards to be integrated into international community.

The main part. The analyses of water bodies monitoring tasks revealed what information is needed for decision making. This is the basis of information layers for 3D cadastre of water objects. In order to ensure the most effective decision-making on the use of water objects, the 3D cadastre must contain information about: 1) the relief of the bottom of water bodies and their coastline; 2) the state of the banks of reservoirs and hydrotechnical buildings; 3) volumes and localization of groundwater, lithology of water-bearing rocks and bottom sediments; 4) water consumption and flow velocity; 5) temperature, transparency, chemical and biological composition of water, concentration of pollutants; 6) land use and construction within the boundaries of water objects and water protection zones; 7) rights to water objects; 8) composition and condition of flora and fauna; 9) payment for the use of water objects; 10) the regulatory status of water objects.

The above-mentioned data form the main structural content elements of a conceptual model of the 3D cadastre of water objects, its information layers. According to the peculiarities of the nature of water objects, the entire array of information about water objects is united into two large groups: immanent and transcendental information. Immanent information, including geospatial and factual information, directly reflects the characteristics of water objects. It has a set of quantitative and qualitative indicators. Qualitative indicators, depending on the GIS system, are transformed into codes and classes using algebraic equality. In contrast to immanent, transcendental information is not the property of a water object. This information has no fixed values, and is contained in other cadasters and registries. In this case, the basic structural element of the 3D cadastre of water objects is geospatial three-dimensional data, which forms the basis for the recording of other information necessary for monitoring. The structural-logical model of information layers for the 3D cadastre of water objects is shown in Fig. 1.

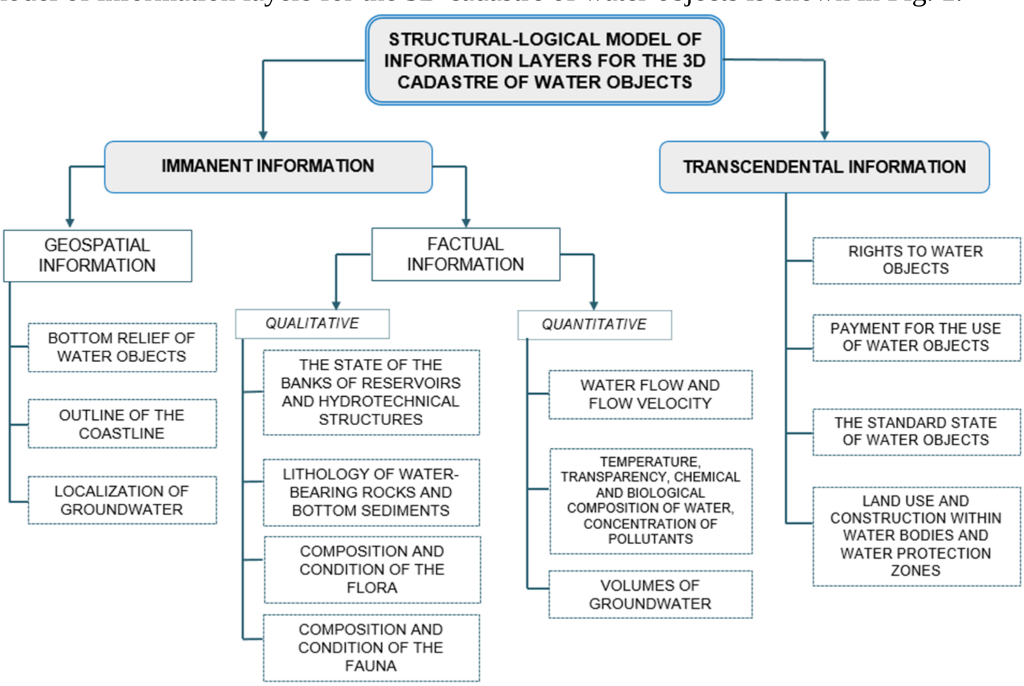

Figure 1. Structural-logical model of information layers for the 3D cadastre of water objects

The analysis of scientific works in the field of 3D cadastre shows that the three-dimensional description of water objects, unlike real estate, is not investigated properly (Aien, 2013, 33; Stoter, 2004, 3). Therefore, the established practice of constructing 3D cadastre of water objects is absent. In view of this, the main source of technological information when creating such a system are international standards for work with geospatial data, which were harmonized with Ukrainian legislation.

According to them, the 3D cadastre of water objects should be constructed on an object-oriented data model «The Geodatabase», based on the principle of relational tables. This model uses personal or multi-user relational databases and, in comparison with other data models, has significant advantages for cadastral systems. All kinds of information are possible to be included in such cadastral systems due to the geographic data sets of the three main types: feature classes, raster databases and tables (Zatserkovny, Buracheck, Zheleznyak and Tereshchenko, 2014, 385).

Since the 3D cadastre of water objects is based on the object-oriented data model «The Geodatabase», we have used a unified modeling language (UML) for the description of the systems elements (Stoter, 2004, 3). The structured UML-diagram of the 3D water cadastre model is created using open-source software Dia (diaw.exe.0.97.2) (Fig. 2).

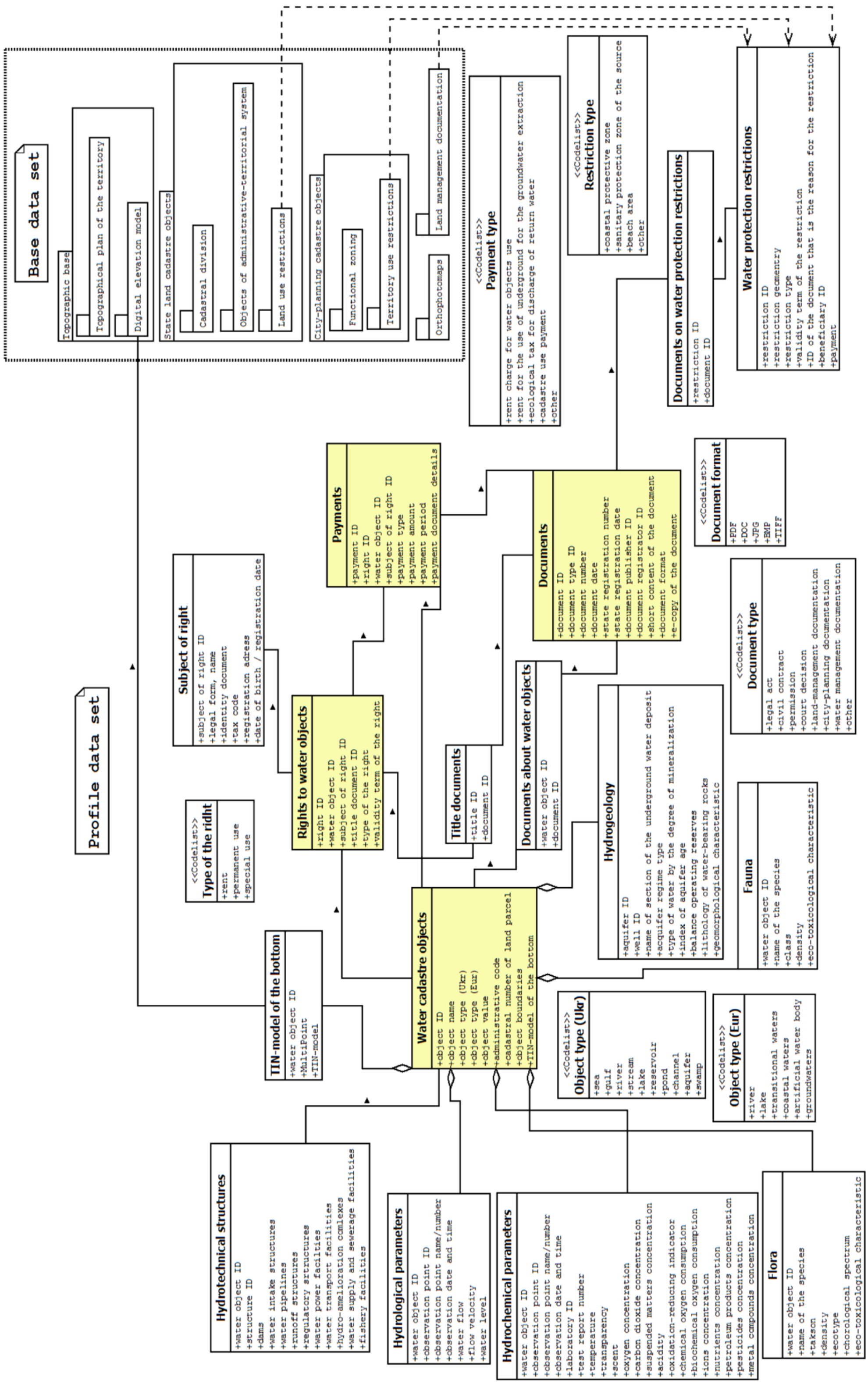

Figure 2. UML-diagram of the 3D water cadastre model

According to requirements of INSPIRE, the structure of the data model «The Geodatabase» includes the following components: base data set, profile data set and metadata. The base data set defines the spatial organization of the system and includes the following packages: «Topographic base» (including subpackages «Topographical plan of the territory» and «Digital elevation model»), «State land cadastre objects» (subpackages «Cadastral division», «Objects of administrative-territorial system» and «Land use restrictions»), «City-planning cadastre objects» (subpackages «Functional zoning» and «Territory use restrictions») and «Orthophotomaps». For the purposes of the water cadastre, the package «Land management documentation» is also included in the base data set.

As defined in law project «About the national infrastructure of geospatial data», profile data sets represent a set of thematic geospatial data that can be grouped into clusters (groups of classes associated with a common function). For constructing a conceptual model of the 3D cadastre of water objects, an object-oriented principle of data organization was used. This principle allows characterize the positions of each block of information in the system and reproduce the logical interrelations between them. In accordance with this principle, an object is a real or abstract entity that has its own state, behavior and individuality (Zatserkovny, Buracheck, Zheleznyak and Tereshchenko, 2014, 385). The state of the object is characterized by the attributive data associated with it, and its behavior is realized in the form of functional relations (Zatserkovny, Buracheck, Zheleznyak and Tereshchenko, 2014, 385). In the cadastral system, such objects are basic units of account. In this study we deal with water objects, as well as related rights, documents and payments. Objects having a common structure and behavior are grouped into classes (Zatserkovny, Buracheck, Zheleznyak and Tereshchenko, 2014, 385). Thus, the conceptual model of the 3D cadastre of water objects contains four main classes: «Water cadastre objects», «Rights to water objects», «Documents», «Payments» (they are highlighted in yellow color in Figure 2). To improve system stability, we have added two secondary classes «Documents about water objects» and «Title documents». These secondary classes are meaningfully connected with the main classes by associative correlations.

The class «Water cadastre objects» contains information about the identifiers of water objects, their names, type, value (local or state), administrative code, cadastral numbers of land parcels under the water objects, boundaries of objects and TIN-model of the bottom. The type of water object is determined according to both European and Ukrainian classification, supplemented by the section «swamps». To increase the speed of the system, the subclass «TIN-model of the bottom», which is part of the class «Water cadastre objects», is allocated to a separate entity associated with the package «Digital elevation model». The class «Water cadastre objects» is subdivided into subclasses «Hydrotechnical structures», «Hydrological parameters», «Hydrochemical parameters», «Flora», «Fauna» and «Hydrogeology». The class «Rights to water objects» is associated with the classes «Water cadastre objects», «Title documents», «Subjects of right» and «Payments», as the fee is charged by the subject of the right for use of a particular water object, as evidenced by a certain title document. The class «Documents» is associated with other structural elements of the system through relevant secondary entities: through «Title documents» with the class «Rights to water objects», through «Documents about water objects» with the class «Water cadastre objects», through «Documents on water protection restrictions» with the class «Water protection restrictions». Information in the class «Water protection restrictions» comes from the packages «Land use restrictions» (State land cadastre), «Territory use restrictions» (City-planning cadastre) and «Land management documentation». Metadata are represented in the model in the form of links between structural elements and describe the structure and properties of information. They are intended for the maintenance of catalogs of geoinformation resources and the provision of automated search and evaluation processes for geospatial data by users (according to Scientific research institute of geodesy and cartography). Abovementioned structure of the conceptual model of the 3D cadastre of water objects describes the complex of functional interconnections of the system. These functional interconnections can have differential access mode.

During the study, it was created geospatial data bases for the 3D water cadastre on the territory of Kyiv using the ArcGIS software from ESRI Company. Data sets were created in the ArcMap environment, and 3D models of water objects were visualized in the ArcGlobe module. The choice of software is due to the fact that the ArcGIS software is adapted to create object-oriented models, since they were firstly introduced by ESRI.

The effectiveness of the 3D cadastre of water objects in Kyiv was calculated by forecasting revenue and expenditure. The expenses of implementing the 3D cadastre included expenses for technical support, the creation and filling of the database, maintaining the functioning of the system in the normal mode. They were compared with the existing costs of maintaining the State water cadastre in Kyiv. The obtained result illustrates that conducting a united city 3D cadastre of water objects is much more advantageous from an economic and managerial point of view. The loss of local budget revenue was also estimated, due to incomplete information needed to make adequate decisions on the use of water facilities.

In order to determine self-sustainment of 3D cadastre of water objects, cash inflows, which would be generated by the system, were projected. Such cash flows are proposed to be obtained from administrative services providing information. Efficiency was calculated on the basis of providing access to information through cloud GIS with a differentiated access mode and payment. Calculation was carried out using the method of discounting cash flows to access the net present value (NPV) of the system, according to the Act of Ministry of Finance of Ukraine «On approval of the procedure for assessing the financial condition of a potential beneficiary of an investment project».

As the initial data for calculation the following conditions were accepted:

1. Cash flow that will be generated by the project during the year - UAH 3 749 500.00 (144 992.27 $).
2. The cost of the project during the year - 2 600 000.00 UAH (100 541.40 $).
3. Discount rate - 5% (Koval, 2010, 11).
4. The loan cost - 6 000 000.00 UAH (232 018.60 $) (the cost of technical support of the system).
5. The period covered by the loan is 7 years.

The calculation of the project NPV is shown in Table 1.

The calculation demonstrates that during the seventh year the 3D cadastral system becomes self-sustaining, in accordance with the requirements of INSPIRE.

At the final stage, the testing of the developed 3D cadastre model was carried out on the basis of an assessment of three project decisions regarding the use of water objects in the city of Kyiv: 1) the project of removal of the gas pipeline to the bottom of the Verblud gulf of the Dnipro river; 2) a project of urban development of a land plot on which there is an artificial lake Nebrezh; 3) a project of urban development of a land plot on the Antonovicha street, 52-54, on which there is an artificial lake that was formed during the construction process. We evaluated the effectiveness of the projected solutions, and predicted expected one in the presence of a 3D cadastre of water objects. The calculations prove that structuring information on the proposed model of the 3D cadastre of water objects leads to increasing the efficiency of decision-making on the use of water objects (Petrakovska, Dubnytska, 2018, 374).

Table 1. The calculation of the NPV of 3D cadastre of water objects in Kyiv

Year	Actual cash flow, UAH / year	Discounted cash flow, UAH / year	Repayment of obligation
1	-4 850 500.00 (-187 567.67 $)	-5 093 025.00 (-196 946.10 $)	-6 000 000.00 (232 018.60 $)
2	-3 943 525.00 (-152 495.17 $)	-4 140 701.25 (-160 119.92 $)	-4 905 238.10 (-189 684.40 $)
3	-2 794 025.00 (-108 044.30 $)	-2 933 726.25 (-113 446.50 $)	-3 862 607.71 (-149 366.10 $)
4	-1 784 226.25 (-68 995.60 $)	-1 873 437.56 (-72 445.38 $)	-2 869 626.39 (-110 967.76 $)
5	-723 937.56 (-27 994.49 $)	-760 134.44 (-29 394.22 $)	-1 923 929.90 (-74 397.91 $)
6	389 365.56 (15 056.67 $)	408 833.84 (15 809.51 $)	-1 023 266.57 (-39 569.47 $)
7	1 149 500.00 (44 450.89 $)	816 928.19 (31 590.42 $)	651 436.22 (25 190.88 $)

Conclusion. According to the results of the study, the following conclusions were made:

1. Due to specifics of water objects the 3D cadastre is the most suitable instrument for their monitoring.
2. 3D water cadastre includes both immanent and transcendental information, which determines its information layers' structure.
3. The object-oriented data model «The Geodatabase» is the optimal environment for developing the 3D cadastre of water objects.
4. During the seventh year the 3D cadastre of water objects in Kyiv becomes self-sustaining due to cash flows obtained from administrative services providing access to information through cloud GIS with a differentiated access mode and payment.
5. The proposed information and functional interconnections of the 3D cadastre of water objects allows to increase the efficiency of decision-making on the use of water objects.

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