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DAM BREAK FLOODING SIMULATION USING A DEM CONSTRUCTED FROM LIDAR DATA

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Abstract. A dam breach is one of the most dangerous hydraulic incidents, capable of causing large-scale flooding and significant damage to settlements, infrastructure, and the environment. With the growing number of hydraulic structures and increasing climate-related risks, accurate modeling of such events has become an urgent and relevant task. This study presents a numerical simulation of flood propagation based on the reconstruction of the historical dam failure at the Voroshilov Reservoir (Almaty Region, Kazakhstan), carried out using the Flood Simulation module in ArcGIS Pro 3.4. The Flood Simulation module is based on the shallow water equations and includes hydrodynamic modeling of flood wave propagation, taking into account high-resolution terrain topography. The input data for simulating flooding near the Voroshilov Reservoir consisted of a high-precision digital elevation model (DEM) constructed from LiDAR data collected by an unmanned aerial vehicle (UAV). Two flood scenarios were modeled: the first recreated the parameters of the actual event, in which the reservoir was filled to about half capacity; the second represented a hypothetical situation in which the reservoir was completely full. In both cases, visualizations of the flood development stages were generated. According to the results of the second scenario, the consequences of flooding could be more severe, with the nearby road submerged and floodwaters approaching the highway and adjacent buildings. The results confirm the effectiveness of using LiDAR-derived DEMs and demonstrate the practical applicability of the Flood Simulation module for risk assessment, flood mapping, and planning damage mitigation measures.

Keyword: LiDAR data, digital elevation model, dam failure, flood modeling, hydraulic structures

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ЛИДАР ДЕРЕКТЕРІ НЕГІЗІНДЕ ҚҰРЫЛҒАН ЖЕРДІҢ САНДЫҚ ҮЛГІСІН ПАЙДАЛАНЫП БӨГЕТ БҰЗЫЛҒАН КЕЗДЕГІ СУ ТАСҚЫНЫН МОДЕЛЬДЕУ

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Аннотация. Су қоймасы бөгетінің бұзылуы – елдімекендерге, инфрақұрылымға және қоршаған ортаға айтарлықтай залал келтіретін, ауқымды су тасқынына әкелетін ең қауіпті гидротехникалық апаттардың бірі болып табылады. Гидротехникалық құрылыстар санының өсуі және климаттық тәуекелдердің артуы мұндай апаттардың салдарын дәл модельдеуді өзекті міндетке айналдыруда. Осы зерттеуде Қазақстан Республикасының Алматы облысында орналасқан Ворошилов су қоймасы бөгетінің тарихи бұзылуын қалпына келтіре отырып, ArcGIS Pro 3.4 бағдарламасындағы Flood Simulation модулі көмегімен су басу үдерісі сандық түрде модельденді. Flood Simulation модулі таяз су теңдеулеріне негізделген және су тасқыны толқынының таралуын жоғары дәлдіктегі жер бедері рельефін ескере отырып гидродинамикалық модельдеуді жүзеге асырады. Ворошилов су қоймасы маңындағы аумақтың су басуын модельдеу үшін бастапқы деректер ретінде ұшқышсыз ұшу аппараты арқылы алынған лидарлық түсірілім негізінде құрылған жоғары дәлдіктегі цифрлық рельеф моделі қолданылды. Зерттеу барысында екі сценарий есептелді: біріншісі су қоймасы жартылай толтырылған кезде орын алған нақты жағдайды қайта жасады, ал екіншісі – су қоймасының толық толуы жағдайындағы гипотетикалық жағдайды модельдеді. Екі жағдайда да су тасқынының даму кезеңдері көрнекі түрде бейнеленіп, екінші сценарийде су деңгейінің көтерілуі жақын маңдағы автомобиль жолының су астында қалуына және тұрғын үйлерге жақын орналасқан аумақтарға қауіп төнуіне әкелуі мүмкін екені анықталды. Алынған нәтижелер лидарлық деректерге негізделген ЦМР қолданудың тиімділігін және Flood Simulation модулінің су басу қаупін бағалау, су тасқыны карталарын құрастыру және залалды азайту шараларын жоспарлау ісінде тәжірибелік маңыздылығын дәлелдейді.

Түйін сөздер: лидар түсірілімі, жердің сандық үлгісі, бөгеттің бұзылуы, су тасқынын модельдеу, гидротехникалық құрылыстар

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МОДЕЛИРОВАНИЕ ЗАТОПЛЕНИЯ ПРИ ПРОРЫВЕ ПЛОТИНЫ С ИСПОЛЬЗОВАНИЕМ ЦМР, ПОСТРОЕННОЙ ПО ЛИДАРНЫМ ДАННЫМ

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Аннотация. Прорыв плотины представляет собой одно из наиболее опасных гидротехнических происшествий, способных вызвать масштабное затопление и нанести значительный ущерб населённым пунктам, инфраструктуре и окружающей среде. В связи с ростом числа гидротехнических сооружений и увеличением климатических рисков актуальной задачей становится точное моделирование последствий таких аварий. В данной работе на примере реконструкции исторического разрушения плотины Ворошиловского водохранилища (Алматинская область, Казахстан) проведено численное моделирование затопления с помощью модуля Flood Simulation (ArcGIS Pro 3.4). Модуль Flood Simulation базируется на использовании уравнения мелкой воды и включает гидродинамическое моделирование распространения паводковой волны с учётом высокоточной топографии местности. Входными данными для моделирования затопления территории вблизи Ворошиловского водохранилища являлась высокоточная цифровая модель рельефа, построенная по данным лидарной съёмки с беспилотного летательного аппарата. Полученные результаты демонстрируют эффективность использования данных лидарной съёмки при моделировании разрушения плотины с высвобождением всего объёма воды. Проведены расчёты по двум сценариям:

первый воспроизводил реальные параметры произошедшего события, когда водохранилище было заполнено наполовину; второй моделировал гипотетическую ситуацию полного заполнения. В обоих случаях получены визуализации этапов затопления, а для второго сценария, согласно результатам моделирования, последствия могли быть более серьёзными — с затоплением ближайшей автодороги и критическим приближением воды к автотрассе и жилым строениям. Полученные результаты подтверждают эффективность применения ЦМР, построенной на основе лидарных данных, и практическую применимость модуля Flood Simulation для оценки риска, построения карт затопления и планирования мероприятий по снижению ущерба.

Ключевые слова: лидарная съёмка, цифровая модель рельефа, прорыв плотины, моделирование затопления, гидротехнические сооружения

Introduction. There are hund reds of thousands of dams and reservoirs in operation aro und the world, and their number continues to grow. Despite the significant benefits associated with reservoirs (energy, water supply, flood protection, etc.), dam fail ures occur periodically for a variety of reasons - from foundation and design errors to overflow, seismic impacts, or spillway failure. The most severe failures result in a dam failure and the sud den release of a huge volume of water, cau sing flooding in the lower reaches. The largest flood in Kazak hstan in 80 years in 2024 also led to a num ber of dam failure emergencies (https://www.inform.kz/ru/hroniki-navodneniya-kak-regioni-kazahstana-perezhili-nebivaliy-pavodok-949756). The events of the past year have shown that in order to avoid a catastrophic develop ment of events in Kazakhstan, systematic plan ning of protective measures is required with the development of maps of possible flooding in the event of a break through and special plans of action in emergency situations, providing for monitoring, warning and evacuation systems for the population. A key role in these prev entive measures is played by numerical modeling of a da m break through with the calculation of the spread of a flood wave in the event of a hypothetical destruction of the dam, al lowing for an early assessment of flood zones, the time of water arrival and other flood parameters for various scenarios (Ferrari et al., 2023; Gaagai et al., 2022).

There are several approaches to modeling a breakthrough wave – from simplified calculation schemes to full-fledged numerical models of various dimensions (Aureli et al., 2024). In practical hydraulics, one-dimensional (1D) models based on the Saint-Venan t equations (unsteady flow in a channel) are traditionally used. 1D models describe the flow along the main channel of a river, averaged over a cross-se ction, and have been widely used to assess outb urst floods due to their relative simplicity and low computational costs. For example, in the work (Mo et al., 2023) the calculation of the break through wave was performed using the HE C-RAS software which allows for one-dimensional and two-dimensional hydraulic modeling, including calculation of water levels, flow velocity and flooding (https://www.hec.usace.army.mil/software/hec-ras/). However, the 1D approach does not take into account the redistribution of flow in the transverse direction. Outburst floods, especially on flat terrain, are characterized by flow in many directions – water spreads from the breakthrough site, bends around natural elevations and fills the floodplain. Modern outburst flood calculations are mainly performed on the basis of two-dimensional (2D) models that solve a system of fine-scale flow equations in the horizontal plane. In recent years, 2D modeling has actually become a standard tool for calculating the consequences of dam failures (Peramuna et al., 2024). Two-dimensional models allow for the flow of water in all directions and more accurately predict the flood zone on complex terrain. On the other hand, for a detailed analysis of local hydrodynamic processes – for example, the flow structure near a dam or the flow around buildings and terrain during a flood – three-dimensional (3D) models are used, solving the full Navier-Stokes equations for an incompressible fluid with a free surface. 3D models typically use the volume of fluid method to track the water-air boundary and include a turbulent model (Issakhov & Zhandaulet, 2020). Such calculations are extremely resource-intensive, so the 3D approach is used mainly in scientific research or for individual critical zones. However, 3D modeling can provide the most detailed picture of the flow (Akgun et al., 2023).

The main input data for such modeling are Digital Elevation Models (DEM). The accuracy and completeness of the DEM data directly determine the reliability of the final models. The formation of a three-dimensional (3D) surface based on LiDAR survey data is currently considered one of the most accurate methods for constructing DEM and Digital Surface Model (DSM). LiDAR technologies are used to solve a wide range of problems: from the analysis of potential landslide and rockfall zones to precise mapping of urban areas, forestry, hydrology and monitoring of relief changes (Mallet & Bretar, 2009; Shan, Jie ; Toth, Charles K. ; Petrie, 2018).

LiDAR (Light Detection and Ranging) is based on an active remote sensing method where laser pulses are emitted from an aircraft (airplane, unmanned aerial vehicle (UAV), drone), a ground scanner or other platform, reflected off objects and received by a detector. By measuring the pulse travel time, the distance to each point on the terrain is calculated, forming a high-density cloud of three-dimensional coordinates (X, Y, Z), often accompanied by values of the reflected signal intensity (Chen et al., 2017; Liu, 2008). This technology provides accuracy of up to several tens of centimeters, and in some cases even up to the centimeter level, which is extremely important for tasks related to terrain analysis and modeling of natural processes such as landslides and floods (Chen et al., 2017). The high accuracy and detail of LiDAR data make it possible to solve a wide range of complex engineering and scientific problems. One example of application is the formation of a highly detailed digital elevation model to assess slope instability, where the resolution of the resulting DEM directly affects the quality of mapping of potentially hazardous areas. This approach takes into account the factors of slope, exposure, as well as proximity to roads or water bodies, which provides a more accurate forecast of possible displacement zones (Okoli et al., 2023).

Similarly, when constructing a DSM with above-ground objects (buildings, tree crowns), LiDAR technology makes it possible to more reliably determine the height of objects, as well as analyze the internal structure of forests by registering multiple returns. At the same time, the accuracy of constructing three-dimensional surfaces depends not only on the density of the LiDAR survey material, but also on the selected post-processing algorithms. The presence of vegetation, complex terrain and structures can complicate the process if the filtering and classification algorithms are not perfect enough (Chen et al., 2006; Zhang et al., 2016). However, the active development of machine learning and specialized software packages helps to automate many stages of classification and, therefore, facilitates the construction of correct 3D models (Weinmann, 2016). The enhancement of multi-sensor platforms with the addition of photo cameras, thermal imagers, and spectral sensors makes it possible to add additional thematic layers to the DEM, and it is possible to switch from a static DEM to dynamic monitoring, when changes in relief over time (for example, seasonal erosion) are tracked with high accuracy (Marchi et al., 2018; Tarolli, 2014).

The availability of LiDAR imaging technology and accurate surface elevation data has also expanded their use in flood modelling (Muhadi et al., 2020). And at the present time, DEM obtained using LiDAR are considered the most reliable for modeling flooding processes in territories (Papaioannou et al., 2022; Sampson et al., 2016).

The aim of this study is to model the historical event of the Voroshilov Reservoir dam failure (Almaty region, Kazakhstan) and examines the results of modeling the flooding of the territory using the Flood simulation module available in ArcGIS Pro 3.4. The input data was a high-resolution DEM obtained from LiDAR data from an unmanned aerial vehicle.

Materials and methods of research. *Object of study.* Voroshilov Reservoir was located in the village of Baikent, Ili district, Almaty region (Kazakhstan) and was used for irrigation of agricultural areas and fish farming.

On March 30, 2024, at 15:50 local time, the Voroshilov Reservoir dam burst. The water began to flow along the main channel of the Zharmukhamet River, then flowed into ponds in which all the sluices were open. As a result of the dam break, the bowls of two lakes downstream along the Zharmukhanbet River filled up. Two settlements with a total population of over 12 thousand people were at risk of flooding. Some residents were evacuated (https://tengrinews.kz/kazakhstan_news / proryiv-plotinyi-vodohranilischa-bliz-almatyi-nachato-531327).

Images from the Planet satellite constellation (https://www.planet.com/) on the nearest available cloudless days before the breakthrough (March 28, 2024) and after the breakthrough (April 2, 2024) show Figure 1.

Figure 1 – Voroshilov Reservoir according to Planet: on the left – before the dam burst, on the right – after the dam burst.

The cascade-type channel Voroshilov reservoir was located on the Boraldai and Zharmukhambet rivers, 1 km south of the village of Baikent (Chapayevo). According to information provided by the "Ile" production site of Department of Water Resources and Irrigation of the Almaty Region, the construction of this embankment dam dates back to 1910. In 1970, the dam body was reconstructed with concrete lining of the upper and lower pools.

The total volume of the reservoir was 1.36 million m^3, the useful volume was 1.2 million m^3, the length of the reservoir was estimated at 3250 m, the width was 75-150 m, the depth was 2.5-5.8 m. An operational road was laid along the crest of the dam, without fastening. The laying of the upper and lower slopes is 2:1. The fastening of the upper slope was made of precast reinforced concrete slabs measuring 1.5 x 2 m in two rows, with a total coverage area of 500 m^2, the lower slope was fixed with grass crops and reed thickets.

The hydraulic structure of Voroshilov reservoir included:

− The earth dam is 180 m long, the height of the dam is 10 m, the width along the crest is 6 m.

− The spillway structure is tubular (reinforced concrete, 1 m in diameter), combined with a water outlet into the Voroshilovsky channel with a capacity of 2.6 m^3/s, maximum pressure of 4 m, equipped with a metal gate and a screw lift with a manual drive.

− The spillway structure is tubular, combined with a water outlet into the Komsomolsky channel with a capacity of 200 l/s, maximum pressure – 2.6 m, equipped with a metal gate and a screw lift with a manual drive.

− A siphon tubular spillway in the dam body with 2 threads, 300 mm in diameter, with a total capacity of 600 l/s, with a valve installed in the lower pool.

− A catastrophic spillway in the form of a reinforced concrete pipe with a diameter of 800 mm and a capacity of 1 m^3/s.

According to engineering and geological surveys in 2020, the dam body was composed of loams ranging from solid to fluid-plastic consistency; at the base of the dam were light loams ranging from semi-solid to fluid-plastic, which were underlain by coarse sands with inclusions of gravel and pebbles.

The actual volume of the reservoir immediately before the breakthrough, according to the Department of Water Resources and Irrigation of the Almaty Region, was approximately 700,000 m^3.

Input data. The main input data for mode ling the breakthrough parameters and assessing the consequences of flooding is an accurate digital elevation model of the areas located down stream. In order to obtain the DEM, this project conducted a survey using a DJI Matrice 350 UAV equipped with a Zenmuse L1 LiDAR, which is an effective tool for providing 3D data.

Unlike photogrammetry, which uses photography with subsequent approximate restoration of a 3D model, the LiDAR survey met hod uses laser beams that freely penetrate any vegetation and allow obtaining a dense cloud of surface points with reference to coordinates (at a distance of up to 450 m with an accuracy of 5 cm vertically, 10 cm horizontally).

With a 3-axis stabiliz er and a high-precision IMU (Inertial Measurement Unit), the DJI Zenmuse L1 LiDAR provides uniform point distribution even at very high scanning speeds, and can cover up to 2 km² per flight. With th e support of an RGB camera, this ma kes it easy to reconst ruct an absolutely reliable model in true color without inaccurate interpretation of the obtained data.

For the Voroshilov Reservoir, the shooting was carried out at a flight altitude of 30 to 150 meters and included both the empty reservoir bowl and the territories downstream. In total, 1097 frames were received and processed.

LiDAR survey data was processed using Agisoft Meta shape Professional software (https://www.agisoft.com/). Agisoft Metas hape Professional implements a set of meth ods that combine traditional photogrammetric techniq ues and modern computer vision algorithms, providing auto mated construction of three-dimensional models, orthophoto plans and digital terrain models based on a set of overlapping images.

At the i nitial stage of the program, automatic feature det ection is performed using robust operators such as SIFT (Scale-Invariant Feature Transform) or its variations, which allows for correct image matchin g even with significant differences in scale and orientation. Next, block phototriangulation or bundle adjustment is performed, during which both internal camera parameters and external orientation elements (position and tilt angles) are jointly optimized. This iterative procedure minimizes errors and improves overall accuracy.

The next step is Multi-View Stereo reconstruction, where depth maps are calculated for each area of the scene from a set of matched images. Combining the results across all overlapping frames results in a dense point cloud that reflects the geometry of the object in high resolution. Noise is filtered if necessary and points are automatically classified, allowing the ground surface to be separated from buildings, vegetation, and other objects. A polygonal 3D model can be generated from the dense cloud. Most of the editing of the dense point cloud after classification was done manually.

For georeferencing of the obtained model, work with ground control points and flight logs, as well as with global positioning systems, is supported, thanks to which a scaled three-dimensional scene is created in the selected coordinate system. Based on this scene, a DEM is formed, after which ortho-transformation is performed from the original images to obtain an orthophoto plan. Specialized algorithms for seam mosaic and color correction allow you to eliminate gaps and gradient transitions on the finished orthophoto plan. Additionally, Agisoft Metashape Professional has implemented tools for data analysis (measurements, volume calculation), as well as Python and Java interfaces for process automation and integration with other software solutions. Figure 2 demonstrates the technological scheme of data processing in the Agisoft Metashape Professional software. Each block reflects a separate stage – from data preparation to the final export of results.

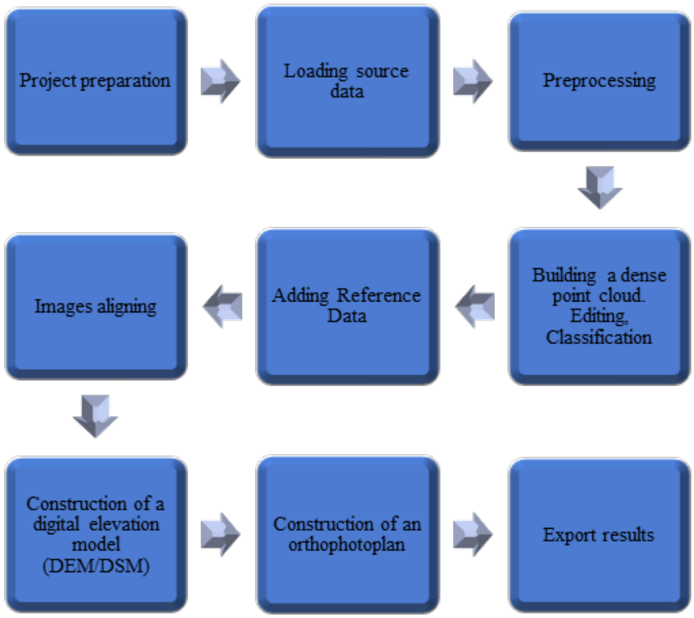

Figure 2 – Technological scheme of processing aerial images in Agisoft Metashape Professional

As mentioned above, the processing process includes photo alignment and building a dense point cloud. Additional functions allow classifying the point cloud, using ground control points, and optimizing the resulting model in a given coordinate system. An example of processing is given below on Figure 3.

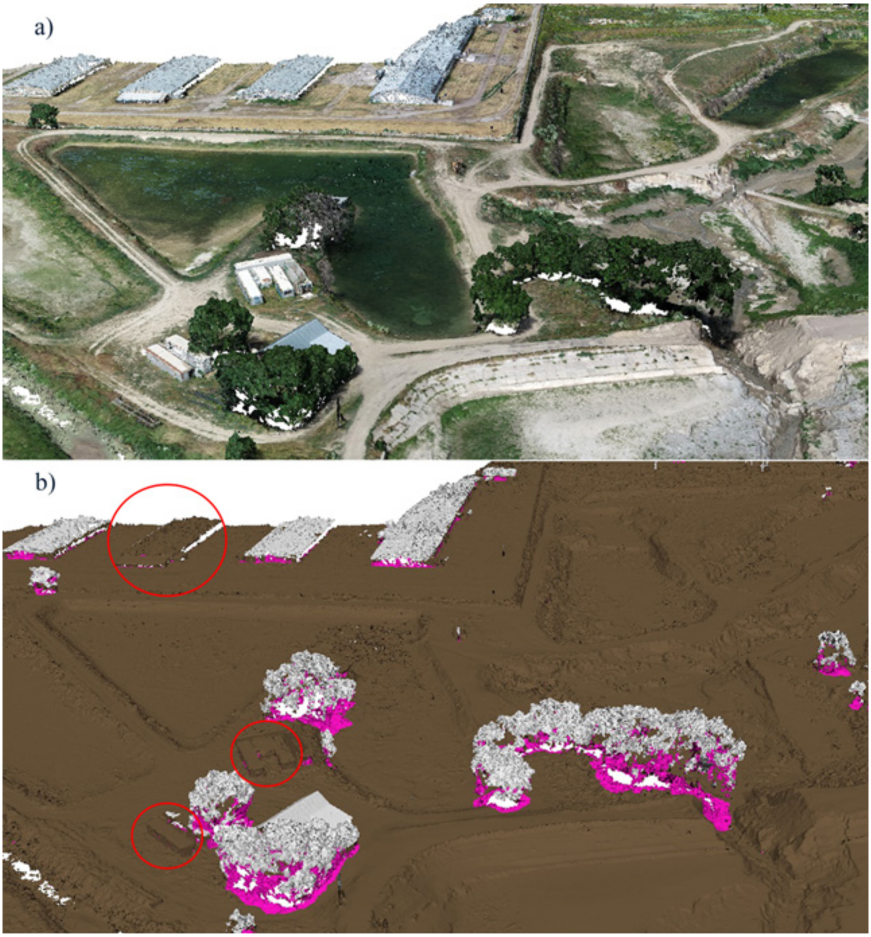

Figure 3 – Processing UAV data in Agisoft Metashape Professional software. Point cloud classification for creating DEM

The point cloud was classified to build the DEM. During automatic classification, the points lying on the ground are highlighted in brown. If you compare two images - a colored point cloud (a) and a point cloud with classification (b), you can see that some objects in the second image are highlighted as relief forms (highlighted with red ellipses). In such cases, the point cloud was edited manually.

An example of reconstruction of a DSM near the destroyed dam of the Voroshilov Reservoir, obtained after processing LiDAR data, is presented below (Figure 4).

Figure 4 – DSM in the area of the dam of the Voroshilov Reservoir

The final DEM with a resolution of 7 cm, obtained from the LiDAR survey data of the Voroshilov Reservoir and its adjacent territory downstream, demonstrates Figure 5.

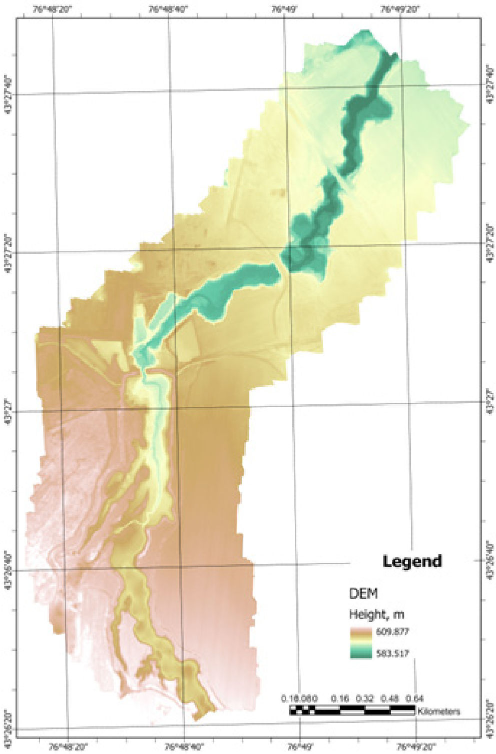

Figure 5 – DEM of the Voroshilov Reservoir and its environs

The analysis of the obtained DEM showed that the actual volume of water flowing out of the reservoir bowl was about 472,000 m^3. This is explained by the fact that part of the water in the southern part of the reservoir was not subject to flowing out and was retained due to the presence of a natural rise in the relief of the lake bottom. In addition, the estimated volume of the lake of 700,000 m^3 was somewhat overestimated, since the process of silting of the reservoir bottom was not taken into account.

Description of the model used. To simulate the flooding of the territory as a result of a dam break using the Voroshilov Reservoir as an example, the Flood simulation module available in ArcGIS Pro 3.4 (https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/flood-simulation-arcgis-pro.pdf) was used. This new ArcGIS Pro tool allows you to simulate the movement and accumulation of water in a 3D scene, allowing you to quickly and on the fly create flood scenarios. This module is based on the use of the shallow water equation within the computational domain. The main input data for the modeling is the DEM and a file containing data on the water depth of the simulated reservoir. The module allows you to specify hydraulic structures elements, such as channels and barriers, and also allows you to set parameters such as the amount and duration of precipitation in a particular area of interest. The minimum amount of required input data facilitates startup and allows you to quickly run various scenarios and visualize the results. This dynamic scenario planning approach provides a flexible and effective decision-making tool for developing flood mitigation strategies.

Computational domain and input data. The parameters of the computational domain were 2750 by 8192 cells with a resolution of 0.259 m, the rotation angle of the computational domain was 129.69°. The initial simulation configuration is presented below (Figure 6).

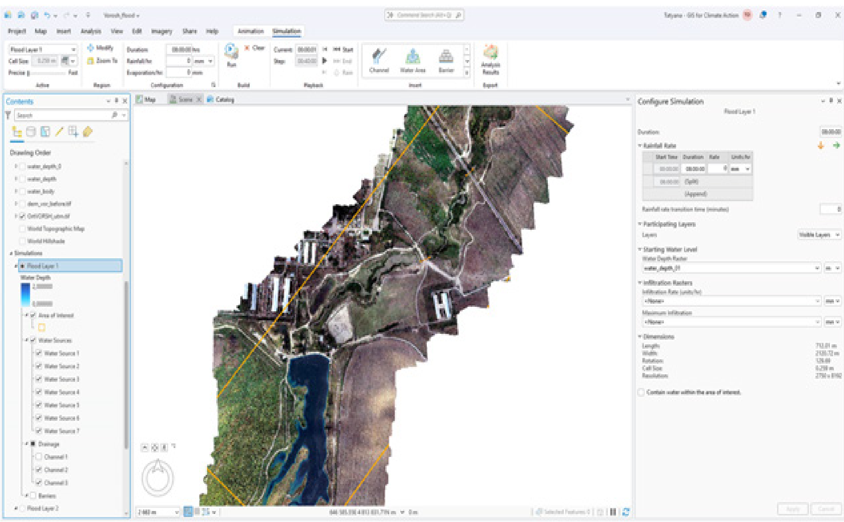

Figure 6 – Initial configuration of the Flood simulation module in ArcGIS Pro 3.4

The DEM of this region obtained from the LiDAR survey was used as a basis for flood modeling after the dam failure. To calculate the input file of reservoir depths (water depth raster), the results of the same survey with available open relief of the lake bottom were used, but first a change was made to the original DEM and the original configuration of the dam before the collapse was restored. The water level was taken as the calculated level of 603 m, which corresponds to the water line according to the space imagery from the Planet satellite for March 28, 2024 (see Figure 1). This approach made it possible to simulate a flood scenario using an exact dam collapse configuration. The dam failure occurred in dry weather conditions, so precipitation data were not added to the model. Two channels, 3.5 and 3 m in diameter, were added to the computational domain to simulate the real situation of the existing riverbed configuration passing under roads in the form of culverts or waterways. The simulation period was set as 8 hours. In order to take into account, the water volume of about 145,000 m^3, which was not included in the computational domain, and to take into account the constant inflow of water along the river, 7 additional sources were specified.

Results. The study included modeling based on two scenarios. The first scenario reproduced the parameters of a real event in which the reservoir was filled to approximately half of its capacity. The calculation results of first scenario for every 40 minutes from the moment of the dam break are presented below (Figure 7).

Figure 7 – Results of flood modeling due to the break of the Voroshilov Reservoir dam

The simulation showed that 6 hours after the start of the simulation, the Voroshilov Reservoir was almost completely empty, with the exception of the southern part of the lake, separated by a natural barrier in the form of an increase in the bottom relief.

The main flow went along the river bed and did not affect the buildings. Also, no overflow of water onto roads in places of culverts was recorded. The results of the simulation correspond to eyewitness accounts that the main volume of the lake flowed out in 5-6 hours, the water went along the existing river bed, overflows on roads, flooding of buildings and structures were not observed.

In the second, hypothetical scenario, it was assumed that the reservoir was filled to its full design capacity. For this scenario, a new depth file was obtained, based on the fact that the water line corresponds to the mark of 604.5 m. To account for the volume of water outside the calculated area, the indicators of 7 additional sources were increased to obtain an additional volume of 233,000 m^3.

The simulation results, which demonstrates Figure 8, showed that with this reservoir volume, the first bypass channel cannot cope with such a volume of water.

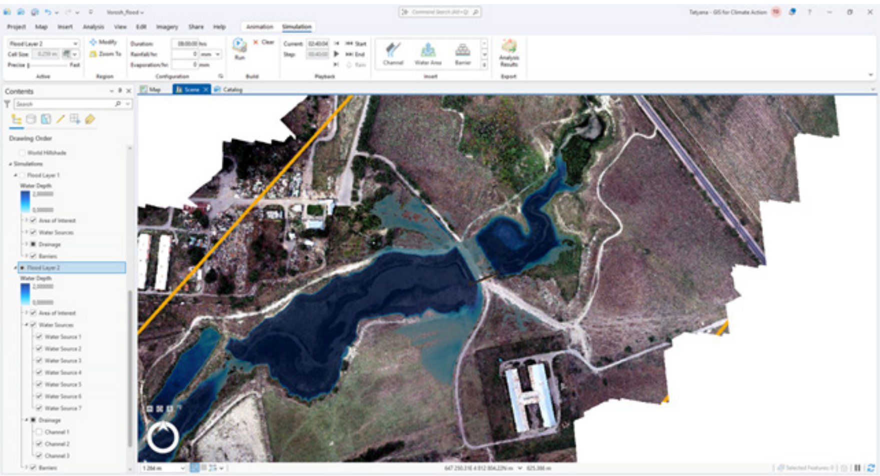

Figure 8 – Results of flood simulation for the full reservoir scenario

After 2 hours and 20 minutes from the start of the breakthrough, an overflow begins onto a dirt road, after 2 hours and 40 minutes the road above the river bed is completely covered with water and the water approaches the nearest buildings. Further modeling of the dynamics of flooding of the territory led to a critical approach of water to the highway, but without overflow and the main flow went along the river bed.

Discussion. The results of the simulations emphasize the critical role of reservoir volume in shaping the extent and severity of downstream flooding. While the first scenario showed limited consequences and matched historical observations, the second scenario illustrated how a fully filled reservoir could dramatically increase flood risk, affecting infrastructure and nearby settlements. The Flood Simulation tool in ArcGIS Pro proved to be highly effective for modeling different flood scenarios. Its ability to visualize the dynamics of flooding with spatial and temporal detail makes it particularly valuable for emergency planning and risk communication.

Although this study did not incorporate parameters such as infiltration or evaporation, the tool allows for these and other customizations in future analyses. Including such factors would further improve the model's realism and reliability under varying climatic and hydrological conditions. This study demonstrates the potential of combining LiDAR-derived DEMs with modern GIS-based flood modeling to support informed decision-making in the design and management of hydraulic infrastructure and civil protection systems.

Conclusion. Formation of a 3D surface based on LiDAR data is a powerful tool both in scientific research and in applied tasks. Complex data processing allows to build highly accurate DEM/DSM, and further analysis to determine important relief parameters and modeling of various processes using them makes it possible to assess the risks of natural and man-made processes and ensure effective planning. At the same time, detailed DEM based on LiDAR data can significantly improve the quality of spatial assessments and forecasts. Reconstruction of the historical dam failure that occurred on March 30, 2024, by modeling the flooding of the territory adjacent to the Voroshilov Reservoir demonstrated the effectiveness of using a high-resolution DEM obtained from LiDAR survey data. The modeling results showed that the main volume of the lake flowed out in 6 hours, the water went along the existing river bed, without spilling onto roads and flooding buildings, which corresponds to the chronology of the development of real events.

Modeling a hypothetical scenario of events developing when the lake is completely filled showed that in such a case, an overflow onto the nearest road would be possible, with water coming critically close to the road and to nearby buildings. The simulations conducted in the Flood simulation tool from ArcGIS Pro showed that although this module does not replace more complex engineering models, it does offer a quick and convenient way to test various scenarios and can be used as a real-time decision-making tool in the planning and design of hydraulic structures.

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