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ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
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ЧФ «Халық»

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В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением, Благотворительный Фонд «Халык»!

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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E.V. Sotnikov[1], O.L. Miroshnichenko[1]*, L.Y. Trushel[1], Sh.I. Gabdulina[2], Ye.Zh. Murtazin[1], 2023

[1]Satbayev University, Ahmedsafin Institute of Hydrogeology and Environmental Geoscience, Almaty, Kazakhstan;

[2]SRK Consulting Kazakhstan, Almaty, Kazakhstan.
E-mail: o_mirosh@mail.ru

FORECASTING THE FLOODING PROCESSES OF URBAN AREAS BY METHODS OF MATHEMATICAL MODELING BY THE EXAMPLE OF PAVLODAR (KAZAKHSTAN)

Sotnikov E.V. — PhD Hydrogeology and Engineering Geology, Senior Researcher of Ahmedsafin Institute of Hydrogeology and Environmental Geoscience, Satbayev University, Almaty, Kazakhstan
E-mail: sotnikov_yevgeniy@mail.ru, https://orcid.org/ 0000-0002-3542-0983;
Miroshnichenko O.L. — candidate of technical sciences (Hydrogeology), Leading Researcher of Ahmedsafin Institute of Hydrogeology and Environmental Geoscience, Satbayev University, Almaty, Kazakhstan
E-mail: o_mirosh@mail.ru, orcid.org/0000-0002-0057-6734;
Trushel L.Y. — candidate of geological and mineralogicalsciences (Hydrogeology), Head of laboratory of Ahmedsafin Institute of Hydrogeology and Environmental Geoscience, Satbayev University, Almaty, Kazakhstan
E-mail: lydmila_y_t@mail.ru, orcid.org/0000-0002-9171-2761;
Gabdulina S.I. — Ph.D student of Satbayev University (Hydrogeology), Consultant hydrogeologist of SRK Consulting Kazakhstan, Almaty, Kazakhstan
E-mail: gabdulinashynar@gmail.com, orcid.org/0000-0001-9997-8903;
Murtazin Y.Zh. — candidate of geological and mineralogicalsciences (Hydrogeology), Deputy Director of Ahmedsafin Institute of Hydrogeology and Environmental Geoscience, Satbayev University, Almaty, Kazakhstan
E-mail: ye_murtazin@list.ru, orcid.org/0000-0002-7404-4298.

Abstract. At present in urban areas the anthropogenic factors impact on groundwater prevails over natural ones. Relevance of the research is determined by the need to make justified management decisions on the drainage of urban areas flooded as a result of industrial and civil construction. The use of mathematical modeling methods allows to simulate changes in hydrogeological conditions during the operation of different variants of drainage systems and choose the optimal drainage scheme. Purpose of the work is to evaluate the efficiency of the designed drainage system with the use of numerical modeling methods to predict flooding process of Pavlodar territory caused by the transformation of the relief as a result of construction and water leaks from the water supply and sewerage. Studies include the development of geoinformation and hydrodynamic models of hydrogeological conditions and solving problems of changes forecasting in groundwater levels as a result of the operation of various drainage systems. Based on the results of the work the determining role of technogenic factors (water leakage from utilities, construction of a dam leading to the CHP, etc.) in groundwater level increase has been confirmed. Four scenarios of the drainage network operation are reproduced, involving various combinations of horizontal drains and drainage wells, the possibility of drainage water into the waste discharge into mined-out open pit. The optimal scheme of water reduction is determined, which consists in the joint use of horizontal drains and existing drainage wells. The performed studies have shown the expediency of using hydrogeological numerical modelling methods in solving problems of evaluating the effectiveness of the designed drainage systems in urban areas.

Keywords: groundwater, flooding, numerical modelling, geoinformation systems

Е.В. Сотников[1], О.Л. Мирошниченко[1]*, Л.Ю. Трушель[1], Ш.И. Габдулина[2], Е.Ж. Муртазин[1], 2023

[1]Satbayev University, У.М.Ахмедсафин атындағы Гидрогеология және геоэкология институты, Алматы, Қазақстан;

[2]SRK Consulting Kazakhstan, Алматы, Қазақстан.

E-mail: o_mirosh@mail.ru

ПАВЛОДАР қ. (ҚАЗАҚСТАН) МЫСАЛЫНДА МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕУ ӘДІСТЕРІМЕН ҚАЛАЛЫҚ АУМАҚТАРДЫ СУ БАСУ ПРОЦЕСТЕРІН БОЛЖАУ

Сотников Е.В. — PhD (Гидрогеология және Инженерлік Геология), Satbayev University, У.М. Ахмедсафин атындағы Гидрогеология және геоэкология институтының аға ғылыми қызметкері, Алматы, Қазақстан

E-mail: sotnikov_yevgeniy@mail.ru, https://orcid.org/ 0000-0002-3542-0983;

Мирошниченко О.Л. — Техника ғылымдарының кандидаты (Гидрогеология), Satbayev University, У.М. Ахмедсафин атындағы Гидрогеология және геоэкология институтының жетекші ғылыми қызметкері, Алматы, Қазақстан

E-mail: o_mirosh@mail.ru, orcid.org/0000-0002-0057-6734;

Трушель Л.Ю. — Геология-минералогия ғылымдарының кандидаты, Satbayev University, У.М. Ахмедсафин атындағы Гидрогеология және геоэкология институтының зертхана меңгерушісі, Алматы, Қазақстан

E-mail: lydmila_y_t@mail.ru, orcid.org/0000-0002-9171-2761;

Габдулина Ш.И. — Satbayev University докторанты; SRK Consulting Kazakhstan гидрогеолог-кеңесшісі, Алматы, Қазақстан

E-mail: gabdulinashynar@gmail.com, orcid.org/0000-0001-9997-8903;

Муртазин Е.Ж. — Геология-минералогия ғылымдарының кандидаты, Satbayev University, У.М. Ахмедсафин атындағы Гидрогеология және геоэкология институтының директорының орынбасары, Алматы, Қазақстан

E-mail: ye_murtazin@list.ru, orcid.org/0000-0002-7404-4298.

Аннотация. Қазіргі уақытта қалалық жерлерде жер асты суларына антропогендік факторлардың әсері табиғи факторларға қарағанда басым. Зерттеулердің өзектілігі өнеркәсіптік және азаматтық құрылыс нәтижесінде су басқан қалалық аумақтарды құрғату мәселелері бойынша негізделген басқару шешімдерін қабылдау қажеттілігімен анықталады. Математикалық модельдеу әдістерін қолдану дренаж жүйелерінің әртүрлі нұсқалары жұмыс істеген кезде гидрогеологиялық жағдайлардың өзгеруін модельдеуге және оңтайлы құрғату схемасын таңдауға мүмкіндік береді. Жұмыстың мақсаты Павлодар қ. аумағын су басу проблемасын шешу үшін жобаланатын дренаждық жүйе жұмысының тиімділігін бағалау болып табылады, бұл құрылыс және су құбыры мен кәрізден судың ағуы нәтижесінде рельефтің өзгеруінен туындаған. Зерттеулер гидрогеологиялық жағдайлардың геоақпараттық және гидродинамикалық модельдерін құруды және әртүрлі дренаж жүйелерінің жұмысы нәтижесінде жер асты сулары деңгейінің өзгеруін болжау мәселелерін шешуді қамтиды. Жұмыс нәтижелері бойынша жер асты суларының деңгейін арттыруда техногендік факторлардың (коммуникациялардан судың жоғалуы, ЖЭО-ға апаратын бөгет салу және т.б.) айқындаушы рөлі расталды. Көлденең дренаждар мен дренаждық ұңғымалардың әртүрлі комбинацияларын, дренаждық суларды карьердің пайдаланылған кеңістігіне жіберу мүмкіндігін қамтитын дренаждық желінің төрт сценарийі қайталанды. Көлденең дренаждарды және бұрыннан бар дренаждық ұңғымаларды ортақ пайдаланудан тұратын суды төмендетудің оңтайлы схемасы анықталды. Жүргізілген зерттеулер қалалық аумақтарда жобаланған дренаждық жүйелер жұмысының тиімділігін бағалау мәселелерін шешуде гидрогеологиялық жағдайларды математикалық модельдеу әдістерін қолданудың тиімділігін көрсетті.

Түйін сөздер: жер асты сулары, су басу, математикалық модельдеу, геоақпараттық жүйелер

Е.В. Сотников[1], О.Л. Мирошниченко[1]*, Л.Ю. Трушель[1], Ш.И. Габдулина[2], Е.Ж.Муртазин[1], 2023

[1]Satbayev University, Институт гидрогеологии и геоэкологии им. У.М. Ахмедсафина, Алматы, Казахстан;

[2]SRK Consulting Kazakhstan, Алматы, Казахстан.

E-mail: o_mirosh@mail.ru

ПРОГНОЗИРОВАНИЕ ПРОЦЕССОВ ПОДТОПЛЕНИЯ ГОРОДСКИХ ТЕРРИТОРИЙ МЕТОДАМИ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ НА ПРИМЕРЕ г. ПАВЛОДАР (КАЗАХСТАН)

Сотников Е.В. — PhD (Гидрогеология и инженерная геология), Старший научный сотрудник. Институт гидрогеологии и геоэкологии им. У.М. Ахмедсафина, Satbayev University. Алматы, Казахстан

E-mail: sotnikov_yevgeniy@mail.ru, https://orcid.org/ 0000-0002-3542-0983;

Мирошниченко О.Л. — кандидат технических наук (Гидрогеология), Ведущий научный сотрудник.

Институт гидрогеологии и геоэкологии им. У.М. Ахмедсафина, Satbayev University. Алматы, Казахстан
E-mail: o_mirosh@mail.ru, orcid.org/0000-0002-0057-6734;
Трушель Л.Ю. — кандидат геолого-минералогических наук (Гидрогеология), Заведующий лабораторией. Институт гидрогеологии и геоэкологии им. У.М. Ахмедсафина, Satbayev University. Алматы, Казахстан
E-mail: lydmila_y_t@mail.ru, orcid.org/0000-0002-9171-2761;
Габдулина Ш.И. — докторант Satbayev University (Гидрогеология), Гидрогеолог-консультант SRK Consulting Kazakhstan, Алматы, Казахстан
E-mail: gabdulinashynar@gmail.com, orcid.org/0000-0001-9997-8903;
Муртазин Е.Ж. — кандидат геолого-минералогических наук (Гидрогеология), Заместитель директора. Институт гидрогеологии и геоэкологии им. У.М. Ахмедсафина, Satbayev University. Алматы, Казахстан
E-mail: ye_murtazin@list.ru, orcid.org/0000-0002-7404-4298.

Аннотация. В настоящее время на городских территориях влияние на подземные воды антропогенных факторов преобладает над природными. Актуальность исследований определяется необходимостью принятия обоснованных управленческих решений по вопросам осушения городских территорий, затопленных в результате промышленного и гражданского строительства. Использование методов математического моделирования позволяет сымитировать изменение гидрогеологических условий при работе различных вариантов дренажных систем и выбрать оптимальную схему осушения. Цель работы заключается в оценке эффективности работы проектируемых дренажных система методами математического моделирования для решения проблемы подтопления территории Павлодара, вызванного преобразованием рельефа в результате строительства и утечек воды из водопровода и канализации. Исследования включают создание геоинформационной и гидродинамической моделей гидрогеологических условий и решение задач прогнозирования изменения уровней грунтовых вод в результате работы различных дренажных систем. По результатам работ подтверждена определяющая роль техногенных факторов (потери воды из коммуникаций, строительство ведущей к ТЭЦ дамбы и др.) в повышении уровня грунтовых вод. Воспроизведены четыре сценария работы дренажной сети, предполагающие различные комбинации горизонтальных дрен и дренажных скважин, возможность переброски дренажных вод в отработанное пространство карьера. Определена оптимальная схема водопонижения, заключающаяся в совместном использовании горизонтальных дрен и уже существующих дренажных скважин. Выполненные исследования показали целесообразность применения методов математического моделирования гидрогеологических условий при решении задач оценки эффективности работы проектируемых дренажных систем на городских территориях.

Ключевые слова: подземные воды, подтопление, математическое моделирование, геоинформационные системы

Introduction

Currently, anthropogenic activities have a significant impact on the environment in general, and groundwater in particular. Intensive construction changes the natural groundwater regime. In turn, flooding processes pose a threat to the safety of buildings and structures. Almost 80 percent of Kazakhstan's territory, more than 200 settlements are potentially flooded (Smolyar, 2017).

Flooding refers to an increase in the groundwater as a result of a natural or artificial increase in the incoming part of their water balance, as well as the emergence of obstacles to their movement. Among the natural causes of flooding, we can distinguish climatic (precipitation exceeds evapotranspiration), geological, topographic (features of the territory relief), hydrogeological (influence of the natural hydrographic network on groundwater regime), etc. Artificial causes of flooding include transformation of the terrain relief, installation of structures in the path of the natural movement of surface and groundwater, shortcomings in the operation of urban water infrastructure leading to leakages of fluid from water-bearing communications, etc.

Using the geomorphological features of the territory, Kazakhstan was zoned according to the degree of flooding and a map of the danger of changing the groundwater table was drawn up (Smolyar, 2017).

It is advisable to use mathematical modeling methods to assess the impact on the state of groundwater of the whole set of causes causing flooding, as well as to develop measures for drainage of the territory. The possibility of solving problems of forecasting changes in hydrogeological conditions under various combinations of natural and artificial factors, as well as reproducing the work of engineering structures makes the mathematical model an integral part of the decision-making process to eliminate the consequences of the urban areas flooding. This is confirmed by studies done around the world.

Mathematical modeling methods are widely used in the development of measures for the drainage of urban areas in Russia. Mathematical models of groundwater based on Visual Modflow are used in the hydrogeological substantiation of construction conditions of high-rise structures in Moscow (Nikulin-Osnovskiy, 2008). For the groundwater-flooded area of Plyustrovo okrug (St. Petersburg), modeling methods were used to analyze different scenarios of dewatering by means of a network of water dewatering wells or drainage systems. To forecast changes in the groundwater regime in areas of intense anthropogenic load and optimize the management of the groundwater hydrosphere on the scale of the city, district planning quarters and local areas, three-level hydrodynamic models of Tomsk area were created on the basis of GMS and FEFLOW (Pokrovsky, 2015). Modeling methods were used in the development of measures to protect against flooding the Omsk metro and adjacent areas. Assessment of the influence of retaining walls construction along the embankment of the Kama River in Perm on the changes in geological, hydrogeological and hydrodynamic conditions was performed by solving the equation of non-standard plan filtration by numerical methods (Purgina et al., 2016). The mathematical model of geofiltration created by Modtech tools was used to study the anthropogenic flooding regime of Shakhty. In order to make managerial decisions to curb the flooding processes which increased after the implementation of the central water supply project in Zernograd (Rostov region), it is proposed to use a numerical hydrogeological model implemented in Visual Modflow. The forecast of changes in the groundwater table as a result of anthropogenic factors in the urban environment for the typical industrial city of Ukraine was performed by the example of Kharkiv using the methods of mathematical modeling.

A three-dimensional mathematical model of groundwater flow has been created to study the impact of groundwater rise on the underground infrastructure (subway tunnels, stations, deep foundations) of urban areas of Milan (Italy) and to assess the effectiveness of various solutions to reduce the danger (Gattinoni et al., 2017). A hydrological model for the suburban Yzeron areas (west of Lyon, France) characterized by intermittent urbanization, is integrated into the hydrological model of the city and considers the relations of surface water, aeration zone water, and groundwater. To describe the urban water cycle of the city of Rastatt (Southwest Germany), a system of interconnected models of water supply, wastewater disposal, aeration zone and groundwater was used. For the city of Ljubljana (Slovenia), a system of mathematical models consisting of interconnected models of urban water supply management, infiltration and exfiltration from sewerage networks, as well as models of the aeration zone and groundwater was created to assess the impact of urban water infrastructure on the aquifers' condition. A numerical model reflecting the interaction of urban infrastructure with groundwater was created for the city of Bucharest (Romania) in order to plan additional hydrogeological studies and measures to protect groundwater, including the modernization of urban water infrastructure (Gogu et al., 2017). The combined use of the hydrogeological model and the stormwater runoff model for the urban development area of Silkeborg (Western Denmark) revealed the mechanism of groundwater feedback with forced infiltration into the drainage system (Kidmose et al., 2015).

Assessment of the risks of flooding in urban areas of the United States is proposed using numerical models that reflect the characteristics of urban ecosystems and take into account the mechanisms of rising groundwater table (Rosenzweig et al., 2021).

Numerical simulation results based on Visual MODFLOW were used in forecasting the impact on groundwater flow of the construction of a highway tunnel over a mountain range in Chongqing (China) (Lv et al., 2022). Numerical groundwater model was used to study the subsidence process in Seoul (Korea) caused by construction work and sewer leaks. (Jo, et al. 2016). Modeling methods were used to study the combined effects of urbanization and climate change on flooding in Kathmandu (Nepal) (Saurav et al., 2021). The simulation-optimization approach was used to build a model of the hydrogeological conditions of the city of Kerman (Iran) which was used to calculate the network of drainage wells and the optimal mode of pumping groundwater (Shourian et al., 2017).

Using a joint surface water and groundwater model for the Southern River Basin (Western Australia), changes in hydrogeological conditions due to urbanization of the area were assessed (Barron et al., 2013). A mathematical model of groundwater in Perth (Australia) was created to quantify the groundwater rise resulting from the use of infiltration wells as an alternative to traditional stormwater drainage (Locatelli et al., 2017). Anthropogenic impacts on groundwater in the Jakarta metropolitan area (Indonesia) were simulated using a system of hydrogeological models including groundwater and aeration zone models (Shaad et al., 2019).

Hydrodynamic groundwater model of Chañar Ladeado (Santa Fe Province, Argentina) is designed to simulate the operation of various drainage systems, including drainage wells and underground closed drainage channels (Zimmermann et al., 2000). To assess the impact of urban infrastructure on the state of groundwater, the development of measures to minimize the risk of flooding areas subject to subsidence, a mathematical model of the hydrogeological conditions of urban areas of Mexico City (Mexico) was created (Mautner et al., 2020).

Analysis of publications allows us to conclude about the effectiveness of using methods of mathematical modeling to assess the impact of various factors on the flooding urban areas and the development of measures for its elimination.

Materials and methods

Pavlodar is one of the largest industrial centers of Kazakhstan. Industrial and civil construction has led to a change in the natural dynamic equilibrium of the water balance and, as a consequence, flooding the built-up areas by groundwater (Fig. 1). Currently, the urban area is characterized by a combination of natural and artificial causes of flooding.

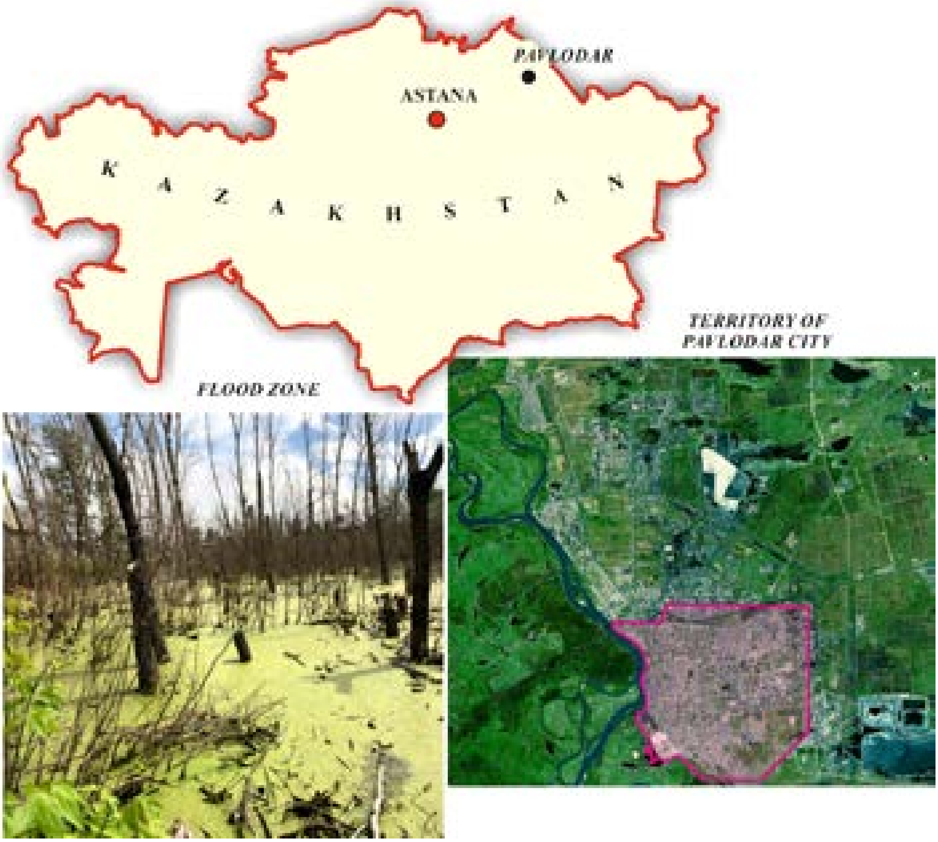

Fig. 1. Location of study area

Natural causes of flooding. Topographical causes are geographical and geometric features of the area. Pavlodar is located on the right bank of the Ertis River within the first terrace above the flood-plain and the adjacent Neogene plain. Absolute surface elevations change from east to southwest from 143.8–147.5m to 110–115m. In the topography of the residential area there are traced kinks and depressions to a depth of 1.5–2.0 m, which accumulate stormwater and groundwater, increasing flooding of residential buildings in the warm period.

Geological causes of flooding are characteristic of the study area. There is a tiered bedding of sands and clays of the Pavlodar Neogene Formation in the eastern part of the city's residential area. The water-bearing sands of the low-pressure aquifer and the overlying clayey sediments of the Pavlodar Formation are not thick. The shallow occurrence of the water table of the Pavlodar Formation, the complex shape of its overlying bed relief, as well as the variability of the lithological composition of rocks in plan and section even in natural conditions contribute to the accumulation of water in the ground near the surface.

Climatic causes are determined by the ratio of precipitation to evapotranspiration. Pavlodar is located in an area of dry steppes with insufficient moisture. Precipitation varies from 95 to 429 mm per year, with an average multiyear rate of 296 mm. During periods of latitudinal (westerly) atmospheric circulation, the amount of precipitation significantly exceeds the average multiyear norm and causes an intensive rise in the spring groundwater table by more than 1.0 m. The average monthly evaporation from the water surface varies between 0.8–7.6 mm. A significant rise in groundwater table in recent years is the result of an increased amount of precipitation (361–376 mm) including abundant rainfall during the warm period.

Artificial causes of flooding. The transformation of the relief and the creation of structures in the path of the natural movement of surface and groundwater leads to changes in the hydrogeological conditions. Causes of flooding are deeply embedded foundations of multi-story buildings; dense building in the groundwater transit and discharge zone; main water supply networks oriented perpendicular to the main direction of the groundwater flow; strengthening of the banks of the Ertis River which reduced the natural discharge of groundwater into the river, etc.

The most pronounced causes of flooding are deficiencies in the operation of urban water infrastructure. The infiltration of water into the aquifer is the result of infiltration of water leaks from the water supply system, heating system, fecal sewerage. According to organizations providing heating, water and wastewater services, the annual loss of water from water-bearing networks is more than 12 million m^3. Moreover, additional groundwater feeding occurs when irrigating vegetable gardens and green spaces, leaks from septic tanks in areas without fecal and storm sewers.

According to long-term observations in the city, the groundwater table has increased by 0.8–14.1 m (Fig. 2). Calculations made on the basis of actual data showed that the infiltration feeding of aquifers varies between 29–187.2 mm/year.

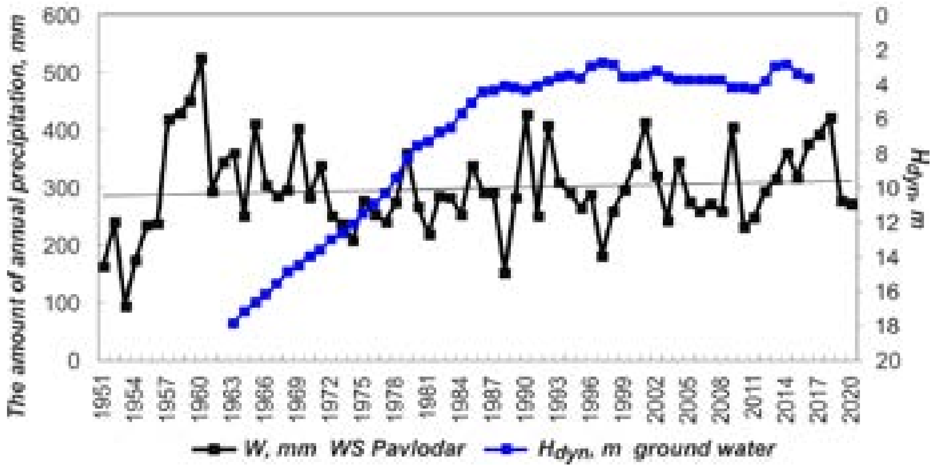

Fig. 2. Dynamic of groundwater level increase in observation well

At a depth of up to 3.0 m, feeding prevails due to precipitation in the amount of 32.2–101.6 mm/year (18–29 % of the annual amount). At a depth of 3-5 m, the total infiltration is much less and amounts to 43–50 mm/year including losses from water-bearing networks — 15.6–16.6 mm/year. At a depth of more than 5.0 m, the prevailing value of infiltration feeding is 36.0 mm/year. About 70 % of infiltration water remains in the aquifer in the city and poses a threat of flooding the built-up area. Groundwater discharge occurs in the Ertis River. The groundwater flow rate in the discharging zone with a width of 2,600 m is 592 m^3/day.

Mathematical model of hydrogeological conditions. The purpose of creating a mathematical model of the hydrogeological conditions of Pavlodar is to assess the effectiveness of the designed drainage systems to solve the problem of flooding the urban area.

The modeling was performed by means of the groundwater mathematical modeling system GMS (Groundwater Modeling System) (https://www.aquaveo.com/software/gms-groundwater-modeling-system-introduction). The input data for creating the model are archival data and the results of fieldwork conducted in recent years.

Underground waters of alluvial deposits of the first terrace above the flood-plain of the Ertis River and the Pavlodar Neogene Formation are distributed within the modeling area. The aquifer of the first terrace above the flood-plain is developed in the southwestern part of the city and has a thickness of 4.2–9.6 m, on average 6.4 m. Water-bearing sediments are represented by medium- and fine-grained sands with filtration coefficients of 3–9 m/day and specific yield of 0.13–0.165.

The aquifer system of Pavlodar Formation deposits in the southwest is overlain by alluvial deposits of the first terrace above the flood-plain, in the east comes to the day surface. Underlain by water-bearing clays of the Kalkaman Neogene Formation. The Pavlodar Formation contains two aquifers composed of fine- and medium-grained sands. The upper one is unpressurized, 2.5–5.5 m thick, rarely 6–7 m thick. The filtration coefficient of water-bearing rocks is 0.55–1.5 and reaches 5.5–9.5 m/day in some places. Specific yield — 0.05–0.15.

The thickness of the separating clays of the Pavlodar Formation is 5–6 m, in some places it reaches 12–16 m. The lower aquifer is low-pressure, unconfined in thickness, which varies from 0.7–0.8 to 4.5–5.0 m. Filtration coefficients of water-bearing rocks are 0.9–4.6 m/day, specific yield is 0.1–0.19. Deposits of the terrace above the flood-plain and the Pavlodar Formation are almost universally overlain by light sandy loam, polymictic fine-grained dusty sands, and less frequently by loams.

Groundwater is fed by infiltration of atmospheric precipitation, leakages from the water supply networks and septic tanks, irrigation water from the territory occupied by vegetable gardens and green spaces. The main expenditure items of the water balance are evaporation and transpiration by plants, outflow to drains and along the outer boundaries of the study area. Moreover, a vertical drainage system consisting of eight wells with a water withdrawal of 850 m^3/day was created in the north-eastern part of the city. Drainage water is discharged into the sewer.

The prevailing direction of groundwater movement is southwest, corresponding to the slope of the terrain to the Ertis River. The values of the groundwater table vary from 143–142 m to 118–120 m. In the northeastern part of the territory, the movement of low-pressure water is radially flowing to the southwest, as well as to the south and northeast.

The simulation area corresponds to the residential area of Pavlodar. The external boundaries are drawn in the west along the Ertis River, in the north — along the contour of water table and schematized by boundary conditions of the third kind reflecting the dependence of the flow rate on environmental conditions. In the north-northwest, south, and east, the boundaries run along stream lines along which the flow rate is zero (Q=0), and are schematized by boundary conditions of the second kind. Laying lines of designed drainage systems are schematized by boundary conditions of the second kind. Drainage wells were simulated by setting point objects of *Well* type corresponding to water wells.

Five layers are distinguished in the section in accordance with the lithological structure of the territory and filtration properties of water-bearing rocks. The upper layer corresponds to cover deposits. The second layer is represented mainly by sands. The third one is distinguished according to the distribution of the lens of water-resistant clay deposits in the eastern part of the modeled area. The fourth layer includes sandy sediments. The fifth layer corresponds to clays of the Pavlodar Formation.

The equations of stationary and non-stationary filtration of groundwater flow in heterogeneous and anisotropic medium are used to solve the problem of groundwater inflow assessment in the drainage network (Langevin et al., 2017). They are implemented using the MODFLOW module of the GMS modeling system.

The study of hydrogeological objects affected by a variety of natural and anthropogenic factors involves the use of a large amount of actual material. Accumulation of data and their processing, solution of tasks of forecasting changes in hydrogeological conditions, and effective analysis of numerical results are possible with the use of geoinformation and mathematical modeling technology (Veselov et al., 2004).

The geoinformation model collects and analyzes primary materials, assesses their completeness and reliability, structures and prepares input data for the mathematical model. Functioning of the hydrogeological object is simulated on the mathematical model created by means of the groundwater modeling system. The results of modeling are converted into GIS formats and complement the previously created geoinformation model.

Geoinformation model of the territory of Pavlodar was prepared with the help of ArcGIS geoinformation system. Based on the results of surveys of specialized hydrogeological organizations, such as Pavlodarhydrogeologiya, Pavlodarenergoproekt in 2007, 2018–2019 maps and sections reflecting the lithological structure of the simulated area, topographic maps, maps of contour of water table and depths of occurrence of groundwater for different periods of time, maps of the hydrological network and others were prepared and digitalized.

To visualize the flooded areas of urban development, a schematic map of the depths of groundwater, in which the areas of the greatest flooding are shown in color. According to their location, the location of drainage networks was determined. The most pronounced flooding of the built-up area along the bend in the terrain and in small depressions, where thin layers of water-bearing sands are spread.

The mathematical model was created by means of the GMS, the groundwater mathematical modeling system. The simulated area in the plan is approximated by a uniform orthogonal grid with a step of 100x100 m. The number of blocks on the X-axis is 95, Y- 84. Four layers are distinguished in the section not including the lower layer of water-bearing clays of the Kalkaman Formation (Fig. 3).

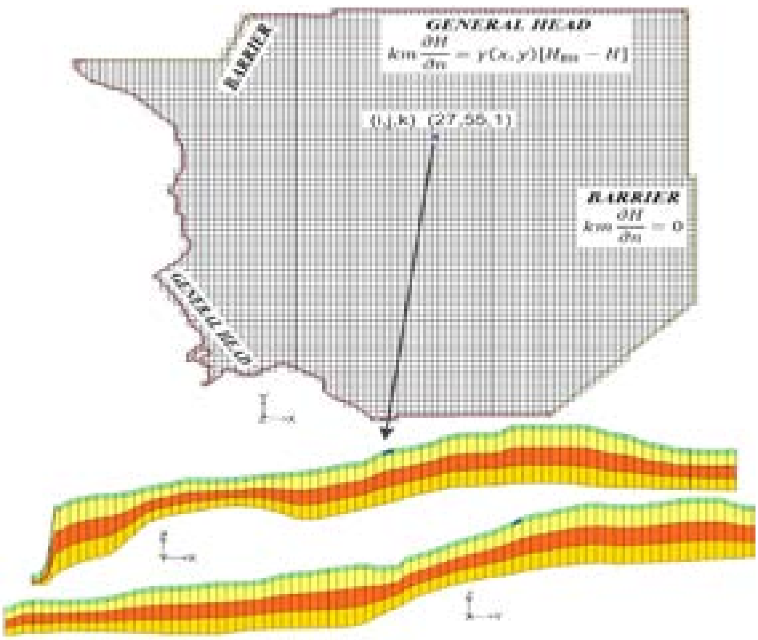

Fig. 3. Grid approximation of modelled area

Absolute elevations of the ground surface and the bottom of the aquifer were set by importing shape-files from the geoinformation system and converting them to the matrices of the overlying bed and bottom of the corresponding layers. The thickness of the first layer of cover deposits averages 1.2 m. The underlying aquifer is divided into 3 layers.

Covers of the filtration parameters of the model were formed for each selected layer. The filtration coefficients for the second and fourth layers change uniformly over the area. In the third layer of the model, an area corresponding to clayey sediments with significantly lower filtration coefficients is highlighted. Values of filtration coefficients of sand sediments vary from 1-10 m/day, for clay sediments are 0.00001 m/day. Horizontal and vertical filtration coefficients are set equal for each sediment type. The values of the parameters lie in the range determined in the process of experimental and laboratory work.

Area feeding was set for the top layer of the model. It was calculated based on actual data of 0.29 m/year, or 0.000795 m/day. When solving the non-stationary task, losses from communication networks, as well as effluents of industrial enterprises were taken into account.

The total evaporation and transpiration coefficient was set to 0.001 m/day. The critical depth of groundwater which begins to evaporate is 2.4 m and was taken from the literature and work experience.

The outer boundaries are represented by *general head*, the boundary conditions of the third kind and *barrier*, a type of boundary conditions of the third kind. The conceptual model coverage is reflected on the created three-dimensional network to form a filtering scheme.

Calibration of the model is carried out to prove the adequacy of the model to the existing natural conditions. In the process, filtration parameters and area feeding were specified. The criterion for the accuracy of the model was the coincidence of the contour of the water table constructed according to the results of modeling and the actual data. The problem was solved in 1990. A satisfactory coincidence of the configuration of isolines was achieved which allowed using the model to solve the forecasting problem of changes in hydrogeological conditions as a result of drainage systems.

Solving forecasting problems. The drainage network was designed using a schematic map of critical areas of flooding entered into the geoinformation model. It was supposed to build horizontal drains and drainage wells in flooded areas of the city.

In the mathematical model, the operation of horizontal drains was reproduced by *drain*, the boundary conditions of the second kind, of drainage wells - by *well*, the boundary conditions of the second kind. The values of conductivity and absolute elevations of drain location were associated with each linear object, the value of water withdrawn and the number of model layer, from which water is pumped - with each point object. It should be noted that when solving the forecasting problems, a boundary was added to the model, which runs along the line of the dam of the water pipeline leading to the CHP in the southern part of the modeled area. The dam was schematized by *barrier*, the boundary condition of the second kind.

The mathematical model simulates four scenarios of drainage network operation, assuming pumping of different volumes of water. The results are presented in the form of maps of the contour of water table and lowering of groundwater table as a result of the drainage system at various points in time.

Results and discussion

Possible changes in hydrogeological conditions under different scenarios of drainage network operation on the territory of Pavlodar were forecasted on the model. The first scenario foresees creation of a system of horizontal drains and operation of existing drainage wells within the flooded areas (Fig. 4).

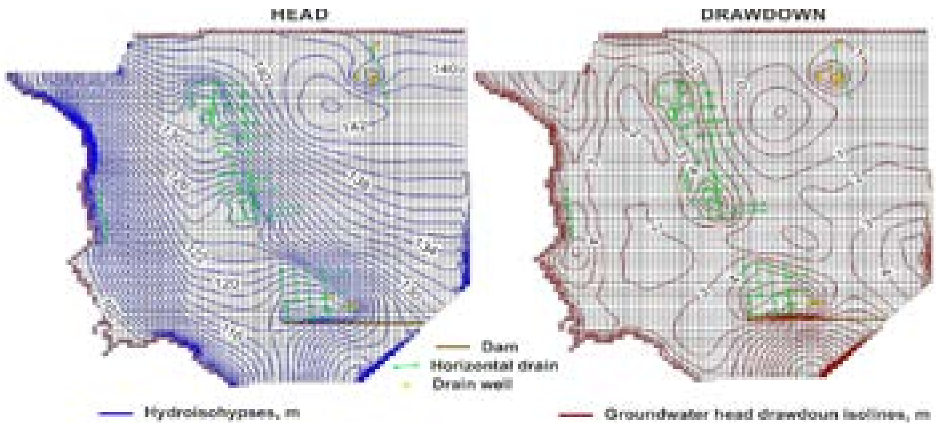

Fig. 4. Groundwater level and Drawdown map by 2030 year, developed based on prediction modelling results of the first scenario of drainage system work

The second scenario involves the construction of a system of drainage wells and two horizontal drains in separate local areas that have favorable conditions for this. 57 project wells were added to the 12 existing wells at three sites. The capacity of existing and project wells varies from 100 to 150 m^3/day (Fig. 5).

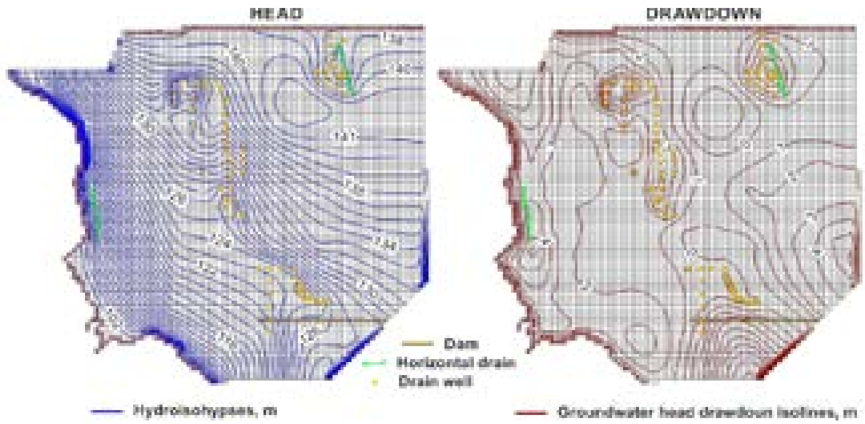

Fig. 5. Groundwater level and Drawdown map by 2030 year, developed based on prediction modelling results of the second scenario of drainage system work

The third scenario is a modification of the second scenario and assumes discharge of pumped water into the waste space of the sand and gravel pit in the northeastern part of the model. The value of additional aquifer feeding set on the model corresponds to the volume of water which is collected by the drainage system (Fig. 6).

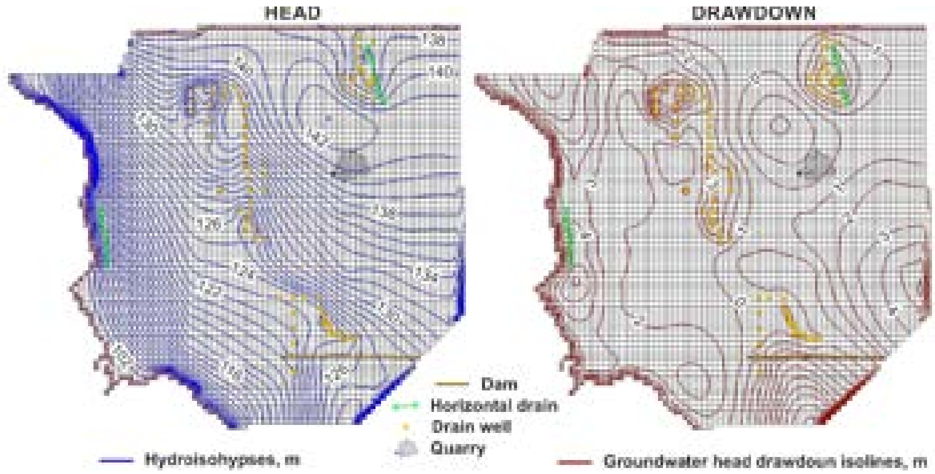

Fig. 6. Groundwater level and Drawdown map by 2030 year, developed based on prediction modelling results of the third scenario of drainage system work

The fourth scenario corresponds to the operation of a combined drainage system including drainage wells and horizontal drains. The effect of the dam which contributes to the backwater effect of the groundwater is taken into account. The depth of the drains is 4 m which agrees with the depth of the bottom of the sands of the upper aquifer. The load on the drainage wells varies from 100 to 150 m^3/day (Fig. 7).

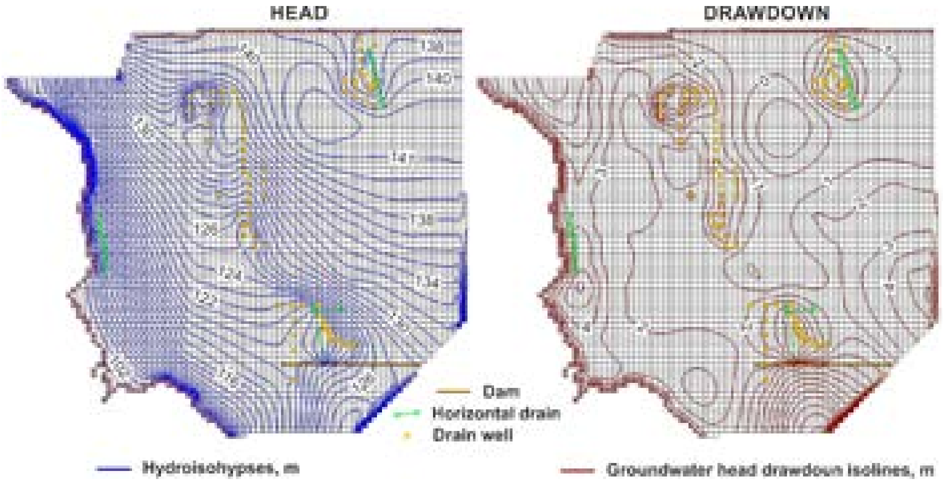

Fig. 7. Groundwater level and Drawdown map by 2030 year, developed based on prediction modelling results of the fourth scenario of drainage system work

According to the results of the solution of forecasting tasks on the created mathematical model of the hydrogeological conditions of Pavlodar, the following conclusions can be made.

Anthropogenic factors play a significant role in the groundwater table rise that cause flooding in parts of the city. To reduce groundwater table and reduce flooding areas, it is necessary to exclude losses from water-bearing utilities which is shown on the model by turning off the supply areas.

Reducing groundwater table to the 3 m mark in the zone of influence of the combined drainage system will reduce the negative impact of groundwater on structures and communications.

Total volume of drainage water from horizontal drainage system operation under the first scenario is estimated in the amount of 22 thousand m^3/day, or 930 m^3/hour. The total volume of drainage water from the system of drainage wells under the second scenario is estimated in the amount of 9.72 thousand m^3/day, or 405 m^3/hour.

Influence of transferring of drainage water collected by the complex drainage system into waste space of the pit is estimated as insignificant and quite admissible.

The most effective dewatering system appears to be the system of horizontal drains and operating wells simulated in the first scenario. But the hydrogeological conditions of the territory, as well as a dense network of surface and underground communications in the city are very difficult to build horizontal drainage.

The dam leading to the CHP has a significant impact on the table rise in the southern part of the study area. The dam and the pipes laid in its body overlapping groundwater contributed to their backwater effect, as well as the accumulation of melted snow and rainfall precipitation. The dam acts as a barrier disrupting the natural outflow of groundwater towards the Ertis River. This is also complicated by the insignificant (up to 2 m) thickness of the first aquifer.

It should be noted that the created mathematical model of hydrogeological conditions of Pavlodar was used for preliminary assessment of various scenarios of drainage system operation. Deciding on its construction will require the creation of a number of detailed local models to calculate the optimal number of drainage wells and their location.

Conclusion

In conclusion, it should be noted that under the prevailing influence of anthropogenic factors on groundwater, the most effective tool for studying hydrogeological conditions is mathematical modeling.

The created mathematical model of hydrogeological conditions is used to assess the effectiveness of the designed drainage systems to solve the problem of flooding the territory of Pavlodar. Implementation of different variants of drainage system operation on the model allowed to choose the optimal scheme of drainage.

Modeling results confirmed the determining role of anthropogenic factors (relief transformation as a result of construction, infiltration of water leaks from the water supply and sewerage system, etc.) in the increase of groundwater table.

The technology of geoinformation-mathematical modeling was used in the process of creating the model. Geoinformation model serves to collect and analyze primary materials, prepare input data for the mathematical model, and display simulation results. Functioning of the hydrogeological object is simulated on a mathematical model.

The conducted studies have shown the effectiveness of using methods of mathematical modeling in solving the problems of designing drainage systems in urban areas.

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