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Satbayev University

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ИЗВЕСТИЯ

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RECOMMENDATIONS FOR THE USE AND DESIGN OF FISH PROTECTION AND FISH PASSING STRUCTURES UNDER GEOLOGICAL CONDITIONS

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Abstract. According to the latest data, the development of aquaculture in Kazakhstan is carried out in four directions: pasture, pond, industrial and recreational. For the past five years, fish production has fluctuated from 410 to 838 tons per year. At the same time, more than 50 % of fish are grown in two regions — Almaty and Turkestan. Natural reservoirs of Kazakhstan are divided into two categories: reservoirs of international and republican significance, which include transboundary reservoirs and reservoirs located in more than one region of Kazakhstan (Caspian Sea, Kapshagai and Shardara reservoirs, K. Satpaev Canal), as well as reservoirs of local significance. Below is a map of the main rivers and lakes of Kazakhstan. There are 48,262 lakes in the Republic of Kazakhstan, of which 45,248 have an area of less than 1 km2. There are 21 large lakes with an area of more than 100 km2. The total area of reservoirs of local importance is about 700 thousand hectares. The largest number of lakes is concentrated in Kostanay and Akmola regions. There are also significant resources in the delta of the Syrdarya and Ili rivers. The aquaculture of Kazakhstan develops according to territorial and climatic principle. The territory of the country is divided into six pond-rearing zones according to the length of the growing season. According to pasture fish farming, all lakes are divided into a zone for growing whitefish, carp and salmon. In particular, carp and whitefish are grown in Central and Northern Kazakhstan, cyprinids, including herbivorous fish, in Southern Kazakhstan, and rainbow trout in the foothill waters of Southern and South-Eastern Kazakhstan. When growing fish, one of the main issues is the protection and release of fish products. On reclamation canals, water intakes and small rivers, the most promising means of protection and passage of fish, arranged in open watercourses and canals. If it is necessary to protect various fish species, it is advisable to use fish protection complexes, which include several types of fish protection structures and devices. The stage-by-stage protection of fish is effective both by simple (auxiliary) and rather complex (main) structures of fish protection structures.

Keywords: fish pass structures, fish protection structures, fish guide rapids, canals, water intakes, fish barriers, new designs of fish pass structures

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ГЕОЛОГИЯЛЫҚ ЖАҒДАЙЛАРДА БАЛЫҚ ҚОРҒАУ ЖӘНЕ БАЛЫҚ ӨТКІЗУ ҚҰРЫЛЫМДАРЫН ПАЙДАЛАНУ ЖӘНЕ ЖОБАЛАУ БОЙЫНША ҰСЫНЫСТАР

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Аннотация. Соңғы мәліметтерге сүйенсек, Қазақстанда аквакультураны дамыту төрт бағытта жүзеге асырылады: жайылымдық, тоғандық, өндірістік және рекреациялық. Соңғы бес жылда балық өндірісі жылына 410 тоннадан 838 тоннаға дейін ауытқып отыр. Бұл ретте балықтың 50 пайыздан астамы екі облыста — Алматы мен Түркістанда өсіріледі. Қазақстанның табиғи су қоймалары екі категорияға бөлінеді: халықаралық және республикалық маңызы бар су қоймалары, оларға трансшекаралық су қоймалары мен Қазақстанның бір облысынан астам аумақтарында орналасқан су қоймалары (Каспий теңізі, Қапшағай және Шардара су қоймалары, Қ.Сәтбаев каналы), сондай-ақ су қоймалары жатады. жергілікті маңызы бар. Төменде Қазақстанның негізгі өзендері мен көлдерінің картасы берілген. Халықаралық және республикалық маңызы бар су объектілері Ауыл шаруашылығы министрлігі Орман шаруашылығы және жануарлар дүниесі комитетінің, ал жергілікті маңызы бар су объектілері жергілікті мемлекеттік органдардың құзырында. Қазақстан Республикасында 48262 көл бар, оның 45248-інің ауданы 1 км2-ден аз. Ауданы 100 км2-ден асатын 21 ірі көл бар. Жергілікті маңызы бар су қоймаларының жалпы ауданы шамамен 700 мың гектарды құрайды. Көлдердің ең көп саны Қостанай және Ақмола облыстарында шоғырланған. Сырдария мен Іле өзендерінің атырауында да айтарлықтай ресурстар бар. Зерттелетін аймақтың геологиялық жағдайына байланысты шұңқырлы, тоғандық және баспалдақ балық асулары бар. Тоған балық өткелдері бір-бірімен қысқа арналар арқылы жалғасқан бірқатар бассейндер болып табылады, олар әдетте бөгет айналасында орналасқан. Баспалдақ балық өткелдері аласа қалқалармен бөлінген бассейндер тізбегі түрінде жасалған, олар таулы аймақтарда салынған. Төмен жылжыған кезде балық бірте-бірте азайып, бір бассейннен екіншісіне ауысады. Жоғары көтерілгенде, балық төмен қалқалардан жоғарыда орналасқан бассейнге оңай секіреді. Балық жолының құлыптары принципі бойынша тасымалдау құлыптарына ұқсас. Олар судың үлкен ағынын қажет етеді, олардың өткізу қабілеті салыстырмалы түрде аз. Қазақстанның аквакультурасы аумақтық-климаттық принцип бойынша дамып келеді. Ел аумағы вегетациялық кезеңнің ұзақтығына қарай алты тоған өсіретін аймаққа бөлінген. Жайылымдық балық шаруашылығына сәйкес барлық көлдер ақ балық, тұқы және албырт балық өсіретін аймаққа бөлінген. Атап айтқанда, Орталық және Солтүстік Қазақстанда сазан мен ақ балық, Оңтүстік Қазақстанда ципринидтер, оның ішінде шөпқоректі балықтар, Оңтүстік және Оңтүстік-Шығыс Қазақстанның тау бөктеріндегі суларында кемпірқосақ форель өсіріледі. Балық өсіру кезінде балық өнімдерін қорғау және шығару басты мәселелердің бірі болып табылады. Мелиорациялық каналдарда, су алғыштарда және шағын өзендерде ашық су ағындары мен каналдарда орналастырылған балықтарды қорғаудың және өтудің ең перспективалы құралдары. Әртүрлі балық түрлерін қорғау қажет болған жағдайда, балық қорғау құрылымдары мен құрылғыларының бірнеше түрін қамтитын балық қорғау кешендерін қолданған жөн. Балықтарды кезең-кезеңімен қорғау балық қорғау құрылымдарының қарапайым (көмекші) және біршама күрделі (негізгі) құрылымдарымен де тиімді.

Түйін сөздер: балық өткелі құрылыстары, балық қорғау құрылымдары, балық бағыттаушы ағындар, каналдар, су алу, балық тосқауылдары, балық өткелдері құрылымдарының жаңа конструкциялары

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РЕКОМЕНДАЦИИ ПО ПРИМЕНЕНИЮ И КОНСТРУИРОВАНИЮ РЫБОЗАЩИТНЫХ И РЫБОПРОПУСКНЫХ СООРУЖЕНИЙ ПРИ ГЕОЛОГИЧЕСКИХ УСЛОВИЯХ

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Аннотация. По последним данным развитие аквакультуры Казахстана осуществляется по четырем направлениям: пастбищному, прудовому, индустриальному и рекреационному. Последние пять лет производство рыбы колеблется от 410 до 838 тонн в год. При этом более 50 % рыбы выращиваются в двух областях — Алматинской и Туркестанской. Естественные водоемы Казахстана делятся на две категории: водоемы международного и республиканского значения, куда входят трансграничные водоемы и водоемы, расположенные более чем в одной области Казахстана (Каспийское море, Капшагайское и Шардаринское водохранилища, канал им. К. Сатпаева), а также водоемы местного значения. Ниже приводятся карта основных рек и озер Казахстана. В Республике Казахстан имеется 48262 озер, из которых 45248 имеют площадь мене 1 км^2. Насчитывается 21 крупное озеро с площадью более 100 км2. Общая площадь водоемов местного значения составляет около 700 тыс.га. Наибольшее количество озер сосредоточено в Костанайской и Акмолинских областях. Значительные реусрсы имеются также в дельте р.Сырдария и Или. В зависимости от геологических условии исследуемого региона различают рыбоходы лотковые, прудковые и лестничные. Прудковые рыбоходы представляют собой ряд бассейнов, соединённых между собой короткими каналами, обычно их устраивают в обход плотины. Лестничные рыбоходы делаются в виде ряда бассейнов, разделённых невысокими перегородками их строят в горных местностях. При движении вниз рыба постепенно снижается, переходя из одного бассейна в другой. При движении вверх рыба без труда перепрыгивает через невысокие перегородки в расположенный выше бассейн. Рыбоходные шлюзы по принципу работы сходны с судоходными шлюзами. Они требуют большого расхода воды, пропускная способность их относительно невелика. Аквакультура Казахстана развивается по территориально-климатическому принципу. Территория страны разделена на шесть рыбоводных зон прудового выращивания, по продолжительности вегетационного периода. По пастбищному рыбоводству все озера разделены на зону выращивания сиговых, карповых и лососевых. В частности, в Центральном и Северном Казахстане выращивают карпа и сиговых, в Южном Казахстане — карповых, включая растительноядных рыб, а в предгорных водоемах Южного и Юго-Восточного Казахстана — радужную форель. При выращивании рыб один из главных вопросов, это защита и пропуск рыбного товара. На мелиоративных каналах, водозаборах и малых реках наиболее перспективны средства защиты и пропуска рыб, устраиваемые в открытых водотоках и каналах. При необходимости защиты различных видов рыб целесообразно применять рыбозащитные комплексы, включающие несколько видов рыбозащитных сооружений и устройств. Эффективна поэтапная защита рыб как простыми (вспомогательными), так и достаточно сложными (основными) конструкциями рыбозащитных сооружений.

Ключевые слова: рыбопропускные сооружения, рыбозащитные сооружения, рыбонаправляющие пороги, каналы, водозаборы, рыбозаградители, новые конструкции рыбопропускных сооружений

Introduction

Most fishways are made in the form of long gentle channels, this allows the fish to get to the other side of the obstacle by rolling (when moving downstream) or jumping (when moving upstream) over relatively low obstacles. The speed of the water flow in such channels should be sufficient to carry the fish downstream, but low enough to allow the fish to continue their way upstream. Depending on the geological conditions of the region under study, there are flume, pond, and ladder fish passes. Pond fish passages are a series of pools connected by short channels, they are usually arranged around the dam. Ladder fish passages are made in the form of a series of pools, separated by low partitions; they are built in mountainous areas. When moving down, the fish gradually decreases, moving from one pool to another. When moving up, the fish easily jumps over low partitions into the pool located above. Fish-way locks are similar in principle to shipping locks. They require a large flow of water, their throughput is relatively small (Goryachev, 2012).

155 species of freshwater fish live in the reservoirs of Kazakhstan. Commercial catches from rivers, lakes, and reservoirs include 52 fish species. In addition, 10 species of fish are grown in Kazakhstan, as well as several sturgeon hybrids. The table below shows the main farmed fish species in Kazakhstan (Joldassov et al., 2019).

Table 1 - Main farmed fish species in Kazakhstan

Common name	Growing area
Whitefish	North-Kazakhstan region
Carp	All of Kazakhstan, except Mangistau
Silver carp white	Almaty, Shymkent, Kyzylorda
Cupid white	Almaty, Shymkent, Kyzylorda
Rainbow trout	Karaganda, East Kazakhstan, Almaty, South Kazakhstan
Siberian sturgeon	Pavlodar, Karaganda, Aktobe, East Kazakhstan, Almaty, South Kazakhstan, Mangystau, Atyrau, West Kazakhstan
Russian sturgeon	Karaganda, Aktobe, Almaty, South Kazakhstan, Mangystau, Atyrau, West Kazakhstan
Sturgeon hybrids	Karaganda, Aktobe, Almaty, South Kazakhstan
Beluga	Atyrau, West Kazakhstan
Stellate sturgeon	Atyrau, West Kazakhstan

In addition, the artificial reproduction of whitefish, sturgeon, and cyprinids (silver carp) is carried out. Burbot planting material is obtained in small quantities. Experimental work is underway on the artificial reproduction of the zander (Lavrov et al., 2003). In 2014, 302 million juvenile fish were reared (Table 2).

Table 2 - Reproduction of juvenile fish

Total, thousand pieces	Juvenile fish reared by species							
	stellate sturgeon	beluga	trout	carp	silver carp	щука	carp	other species
302 059	5 048	1 334	30 196	145 526	8 094	181	36	111 646

The main commercial fish species are rainbow trout and cyprinids. In recent years, they accounted for over 80% of the total production. Now all planting material for trout aquaculture in Kazakhstan is purchased in Europe (Denmark, Poland) or the USA (Howard Mooers et al., 2009).

Wild specimens are used to obtain the products of carp. In recent years, Russian breeds, the Sarboyan carp, and the Altai carp have been brought to the fish hatcheries of Northern Kazakhstan (Haefner et al., 2002).

On reclamation canals, water intakes, and small rivers, the most promising means of protection and passage of fish, are arranged in open watercourses and canals. If it is necessary to protect fish of various fish species, it is advisable to use fish protection complexes, which include several types of fish protection structures and devices (Smirnov et al., 2004). The stage-by-stage protection of fish is effective both by simple (auxiliary) and rather complex (main) structures of fish protection structures (Haefner et al., 2002).

Research methods and conditions

A fairly simple and effective auxiliary means of fish protection and fish passage can be the design solutions for the inlet heads of dreamless water intakes proposed by A.S. Obrazovsky, A.M. Motinov, N.Zh. Zholamanov and others, at which sufficiently effective protection of juvenile fish is provided. For example, a significant fish-protective and fish-producing effect can be obtained by using bottom-fed buckets arranged in flowing water bodies (Haefner et al., 2002). It is recommended that the wall forming the bucket be curved, and the water intake itself should be designed by the reverse bucket scheme with a curved wall.

To ensure a uniform outlet of air along the length of the conduit, it is arranged tapering. Given the complexity of manufacturing pipes of variable diameter, air ducts are made up of sections of different diameters. When calculating the diameters of air ducts within each section, the following values are determined:

airflow through one hole

$$Q_{в.о.} = \mu u_{в.о.} f_0 , \qquad (1)$$

where is the flow rate, is taken equal to 0.60-0.64; \u003d 0.785d02 - cross-sectional area of the hole; number of holes in one section

$$N_c = l_c n / a_n , \qquad (2)$$

where is the length of the section; - number of rows of holes; airflow through the last section

$$Q_{cm} = Q_{в.о.} N_c ; \qquad (3)$$

section duct diameter

$$D_{ci} = \sqrt{\frac{Q_{ci}}{0{,}785 u_{в.о.}}} ; \qquad (4)$$

flow through each section

$$Q_{ci} = Q_{cm}(m + 1 - i) \qquad (5)$$

where is the total number of sections; – serial number of the section; consumption of one compressor working on one of the air duct threads

$$Q_к = n Q_{c1} , \qquad (6)$$

where n=1.4 is the safety factor; – air flow passing through the first section.

The brand of the compressor is determined by the flow rate and the required pressure (Howard Mooers et al., 2009).

At low water intake rates (up to 3 m^3/s), for example, the Asa River, it is advisable to design a fish protection structure such as a flat grid obliquely installed to the direction of the flow. The maximum length of such a grid should not exceed 24–30 m (Joldassov et al., 2023).

For example, for the calculation, it will be necessary, the estimated water intake rate, the minimum length of the protected juveniles, the maximum length of the protected juvenile fish, the water depth in the channel (mesh chamber) Hk, installation angle of the mesh fabric, fish outlet consumption, mesh with cells of size m, wire diameter d, throughput coefficient n, permissible mesh clogging coefficient Kz, etc.

The required area of the mesh fabric is determined by the dependence (Rozanov, 1985).

$$S_c = \frac{Q_B \sqrt{1 + \xi_c + \xi_n}}{u_{1cp} n} K_з K_к ; \qquad (7)$$

where is the hydraulic resistance coefficient of the grid:

$$\xi_c = (92 - 78n)/\mathrm{Re}_a + 0{,}7(1{,}05 - n); \qquad (8)$$

where is the Reynolds number determined for the flow at the input to the grid cell:

$$\mathrm{Re}_a = u_{1cp} a / \nu ; \qquad (9)$$

here is the average filtration velocity at the input to the grid cell:

$$u_{1cp} = \frac{u_{1\max}(\sin\theta + n\cos\theta + 1)}{2(1 + n\cos\theta)} ; \qquad (10)$$

$u_{1\max}$ = 0.2 m/s is the maximum flow velocity at the inlet to the grid cell, determined from the condition

$$u_{1\max} \prec u_{кp}^{\min} \qquad (11)$$

$u_{кp}^{\min} = 14 \cdot l_p^{\min} = 14 \cdot 0{,}015 = 0{,}21$ - critical speed for the minimum size of the protected fish model; =0.78 – coefficient of hydraulic resistance, taking into account the turn of the flow in front of the grid and taken by the following data:

90-θ	60^0	70^0	80^0	90^0
ξ_n	0,55	0,70	0,90	1,10

Кк = 1.2 – coefficient taking into account the shading of the wall by structural elements, taken in the range of 1.05-1.6 and depending on the design solution of the fish protection structure (Vvedensky, 1999).

The mesh length will be

$$L_c = S_c / (H_k - P) ; \qquad (12)$$

where P is the height of the threshold, taken equal to 0.1-0.3.
The cross-sectional area of the fish hatch at the entrance will be equal to (Shkura, 1979):

$$\omega_p = Q_p / u_p , \qquad (13)$$

where $u_p = Ku_{кр}^{\max}$ is the flow rate at the entrance to the fish hatch;

$u_{кр}^{\max} = 14 \cdot l_p^{\max}$ - critical speed for the maximum size of protected juvenile fish (Vvedensky, 1999).

The width of the entrance to the hatchery

$$b_p = \omega_p / H_c . \qquad (14)$$

The width of the fore-chamber will be equal to:

$$b_a = b_{ap} + b_p \qquad (15)$$

where $b_{ap} = L_c \cdot \sin\theta$ - is the width of the chamber (Vvedensky, 2009).

Results

In case of insufficient level differences, devices are used for the forced removal of juvenile fish from the hatchery.

It is recommended to use moving water-jet washers to wash the mesh. The task of calculating the device is to determine the diameter of the collector pipe, dispensing holes, the flow rate supplied to the collector, and the pressure in it.

We have carried out laboratory studies to determine the main parameters of fish guides of fish passage structures. The purpose of the work was to study on a model installation of the operating conditions of diffusion guide thresholds that ensure the movement of fish to fish passages (Yerzhanova et al., 2017).

At modern river waterworks, the efficiency of fish passage facilities is increased by installing special fish guides. The latter makes it possible to achieve a directed movement of fish from the entire width of the tailwater to the place where the entrance part of the fish passage is located. As such devices, guide nets or gratings are used; electric fish barriers; light, sound, pneumatic other barriers; attractive cuts in the bottom; flooded fish-guiding rapids. The operating experience of hydraulic systems with the types of guide devices listed above has shown that the degree of their efficiency is different. So, networks and gratings clog up quite quickly and create backwater. Especially great difficulties with their use arise during periods of ice drifts and water blooms (Vvedensky, 2009).

Disadvantages of electric fish barriers: a narrow range of applications due to the potential difference created in them (the latter is different both for individual fish species and for fish of different sizes and ages of the same breed); the complexity of the design, if necessary, to ensure the passage of the fin and pike, the slope of fish; significant cost of construction and operation.

Fish barriers based on the use of light, sound, ultrasonic and pneumatic stimuli are currently only being studied. There is no experience of their reliable operation (Shkura, 1979).

Attractive cuts (channels) in the bottom are ineffective because they are relatively quickly brought in by bottom sediments.

The accumulated experience of fish guides has shown that in the process of their design and construction it is necessary:

– the design of the fish guides ensured the directional intensive movement of fish of various breeds and sizes to the fish passage structure or fish reservoir under various hydraulic operating conditions of the latter;

– structural elements of the fish guides did not injure the fish;

– fish guides did not interfere with the provision of normal navigation conditions, the passage of floods, ice drift, sludge, and floating bodies;

– the design of the fish guides was simple, easy to use, and economical.

To the greatest extent, these requirements are met by fish-guiding devices such as diffuser thresholds. In the present research work, it is necessary to investigate this type of fish guide using "model" fish, which are used as juvenile fish intended for passage through the fish passage.

Description of the experimental setup

The work is carried out in a mirror hydraulic flume with a width of at least 0.8–1.0 m, a working length of 5–6 m, and a horizontal bottom. The head part of the tray, they are equipped with a damper and a measured spillway. At the beginning of the tray, a model of a spillway low-threshold dam is mounted, having 5–7 identical spans, covered by gates. The central span, which has bulls elongated to a hundred tons downstream, is a fish passage structure (Imanaliyev et al., 2019). To accurately record the movements of juvenile fish, the bottom of the tray should have a grid of 10x10 cm, drawn in dark lines on a light background of its plane. At the end of the tray, a starting chamber for fish is equipped.

The order of the work. The work begins with studying the recreation of fish - their ability to feel the speed and direction of the flow and react to them. To do this, by maneuvering the valve in the head part of the tray, the speed is increased in its steps and, after its stabilization, several "model" fish are released from the starting chamber at each stage. First, the drifting speed is set, that is, such a minimum speed $\vartheta_{сн}$, in the flume at which the drift downstream of juvenile fish begins to be observed, imitating the behavior of adults, and then attracting speeds $\vartheta_{пр}$. After that, such a flow rate is set in the tray so that the average speed in it is $\vartheta_{ср} = 0{,}5 \cdot \vartheta_{сн}$, and the speed in the zone of the fish pass is equal $\vartheta_{пр}$.

Next, the optimal diffuser angle of the thresholds and the height of the fish-guiding thresholds are sought (Hirt C.W., and et all, 2011).

When looking for the optimal diffuser angle, four schemes are examined: without thresholds; with a diffuser angle $\alpha = 20^0, 30^0, 50^0$ (Figure 1). The height of the rapids in each of these three cases is the same and equals 0.3H, where H is the water depth downstream behind the fish passage.

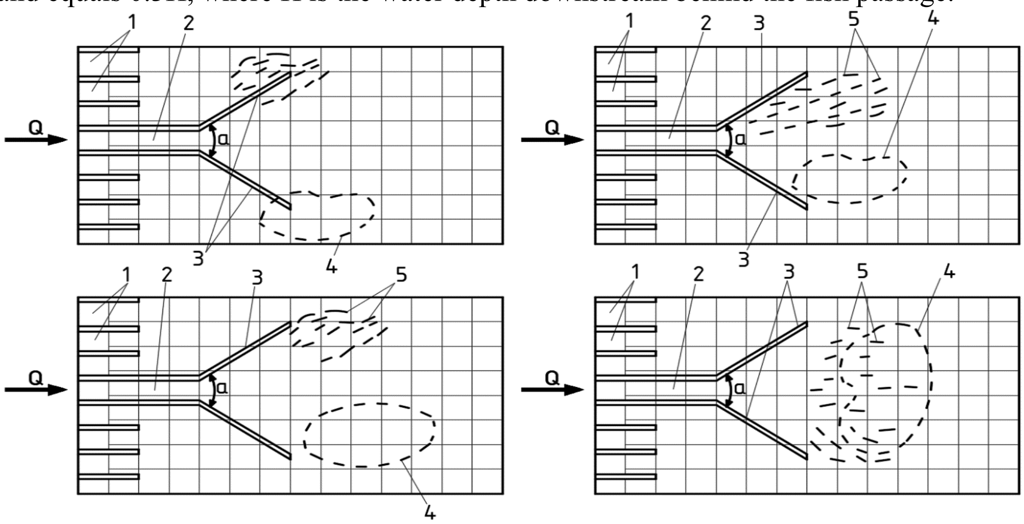

Figure 1 - Location of the main concentrations and zones of fish movement in the zone of the culvert at different angles of diffusivity of the rapids

1 - spillway dam; 2 - fish passage facilities; 3 - fish-guiding rapids; 4 - zones of fish movement; 5 – main concentrations of fish.

Then determine the optimal height of the threshold. To do this, four schemes are also examined with a threshold height taken sequentially equal to 0.15 N; 0.2N; 0.3N and 0.5N, and the diffuser angle taken constantly (Figure 2).

The following aspects of the behavior of "model" fish are taken as criteria for the optimality of the desired threshold parameters (Shkura, 1979):

- the reaction of the flock to the presence of a fish pass;
- flock density (width and total area occupied by the flock);
- the direction of movements of the school and individual fish, the configuration of the area occupied by the school;
- the speed is chosen by the flock and the main places of its concentration.

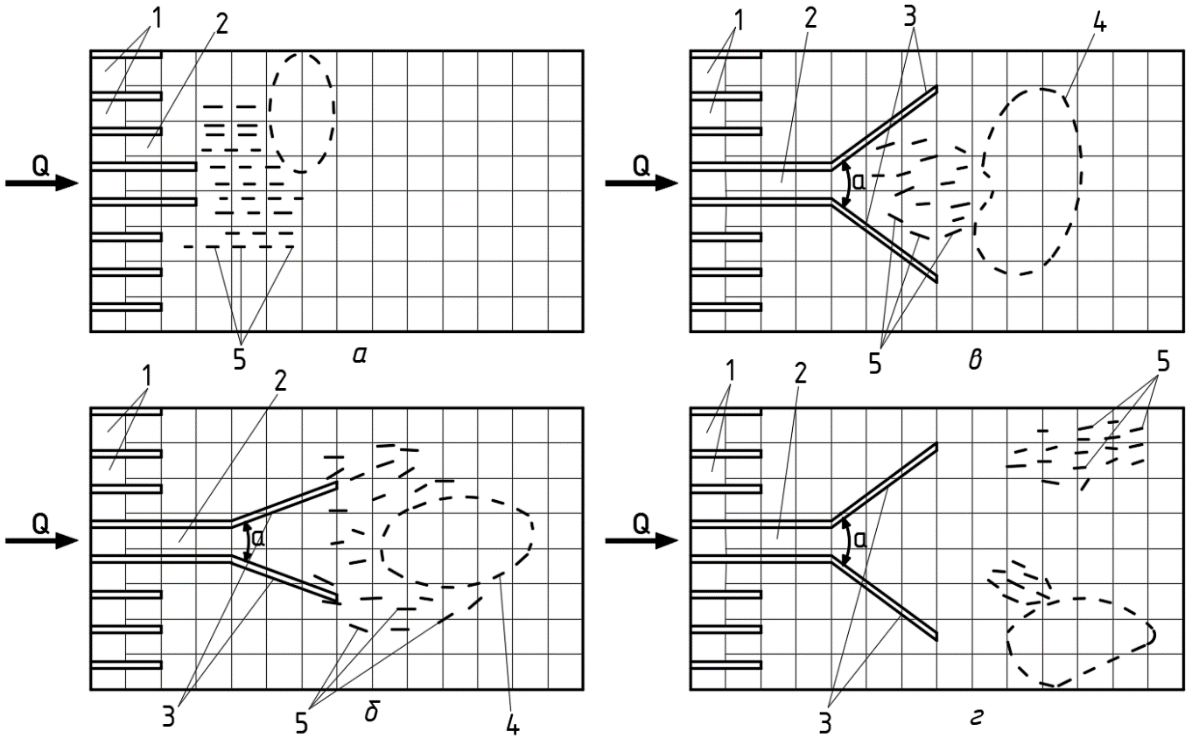

Figure 2 - Location of the main concentrations and zones of movement of fish in the zone of the culvert at different heights of the guide rapids:
a – h P = 0.15H; b - h P = 0.2H; c – h P = 0.3H; d – h П = 0.5H (other designations are the same as in Fig. 1.)

To obtain answers to all these questions, it is necessary to release a flock of fish with an equal number of individuals into the stream from the downstream side of the model dam in each of the eight cases listed above using the starting chamber. The latter are caught with a net from a special aquarium and transplanted into the starting chamber (Lavrov et al., 2003).

We observe the migration of the flock, fixing the main zones of its movement and configuration, using for this a grid drawn on the bottom.

Processing of results. In each of the four experiments, based on the results of observations, the location and concentration of a school of fish are plotted (Howard Mooers, 2009).

Comparison of the behavior of fish in the zone of the fish passage in each case should draw conclusions on the work, answering the following questions (Hirt et al., 2011).:

- what is the height of the rapids, on which the fish practically do not react?
- at what height of the rapids is the reaction of fish to the fish-guiding device the most active?
- at what diffuser angle of the guide rapids is their greatest effect on the directional movement of flocks to the fish passage structure observed?

Discussion of scientific results

The teaching staff of the Taraz Regional University named after M.Kh. Dulaty, under the guidance of Professor S. Koybakov, applied for and received a patent for the invention of fish passage facilities, and conducted scientific research on these models. In the course of experiments in TarRU named after M.Kh. Taking the above logistical theoretical studies of scientists from other countries, experimental work was carried out. In the process of work, the obtained useful models of fish passage structures were taken as a basis (Joldassov et al., 2023).

They consist of separate pools of the following sizes: width – 1.2 ... 13.5, length – 2 ... 2.5 m, water depth – 1.2 ... 1.75 m, drop – 0.3–0 .5 m for sturgeon and carp and 0.15 ... 0.25 m for pike perch, marinka, crucian carp, etc. In the transverse walls separating the pools, pop-up holes are arranged, which are located alternately at the right, then at the left walls (for sturgeon - at the bottom, for carp - at the surface). Hole sizes from 0.2x0.3 to 1x1.5m. And also to increase the efficiency of attracting fish, in addition, on both sides of the stepped trays, a transit part is made in the form of a fast current (Lavrov et al., 2003). This is done for large fish that are used to climbing up on a smooth surface on their own. The required result is achieved by arranging a fish passage structure with ladders in the form of stepped trays, consisting of separate pools of the following sizes: width – 1.2 ... 13.5, length – 2 ... 2.5 m, water depth –

1.2 .. .1.75 m, difference – 0.3-0.5 m for sturgeon and carp and 0.15 ... 0.25 m for pike perch, herring, etc., as well as in the transverse walls separating the pools, float holes are arranged, which are located alternately at the right, then at the left walls (for sturgeon – at the bottom, for carp – at the surface) (Joldassov et al., 2023). And also to increase the efficiency of attracting fish, in addition, on both sides of the stepped trays, a transit part is made in the form of a fast current for large fish that are used to climb up on a smooth surface. Fig. 3 shows a plan of a fish passage facility in the form of stepped flumes and a cross-section of a stepped flume. In Fig. 4, section I–I is a longitudinal profile (Haefner et al., 2002).

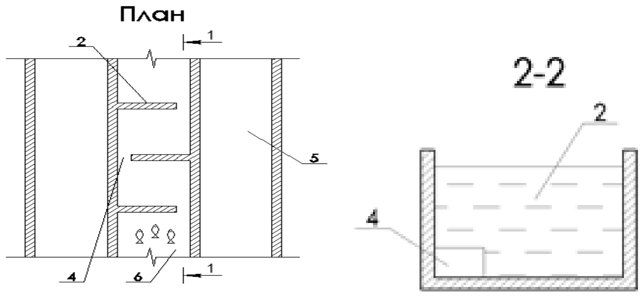

Figure 3. Plan of the fish pass and cross section.

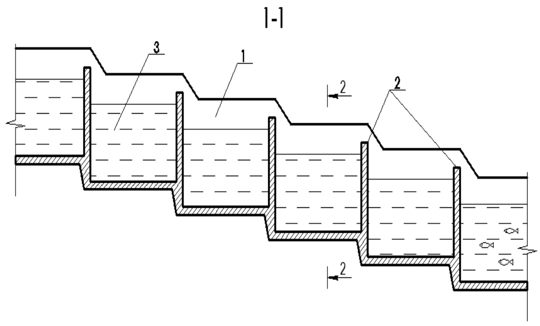

Figure 4. Longitudinal profile of the fish pass.

The fish pass structure consists of a longitudinal wall 1, a transverse wall 2, stepped trays 3, inflow holes 4, and a transit part on both sides of the stepped trays in the form of a fast current 5. The device operates as follows. The device of the fish passage structure made of stairs in the form of stepped trays 3, consisting of longitudinal 1 and transverse 2 walls, is made for the successful passage of fish from one wall to another. Floating holes 4, arranged in the transverse walls 2, located alternately at the right, and then at the left walls – favorably act for the migration of fish upstream (Goryachev, 2012). The transit part in the form of a fast current 5 on both sides of the stepped trays is arranged for large-sized fish that are used to climbing up on a smooth surface without getting into the pool trays (stuped trays).
During laboratory studies, a scaling of 1:100 is shown in Figure 5, and laboratory results were taken.

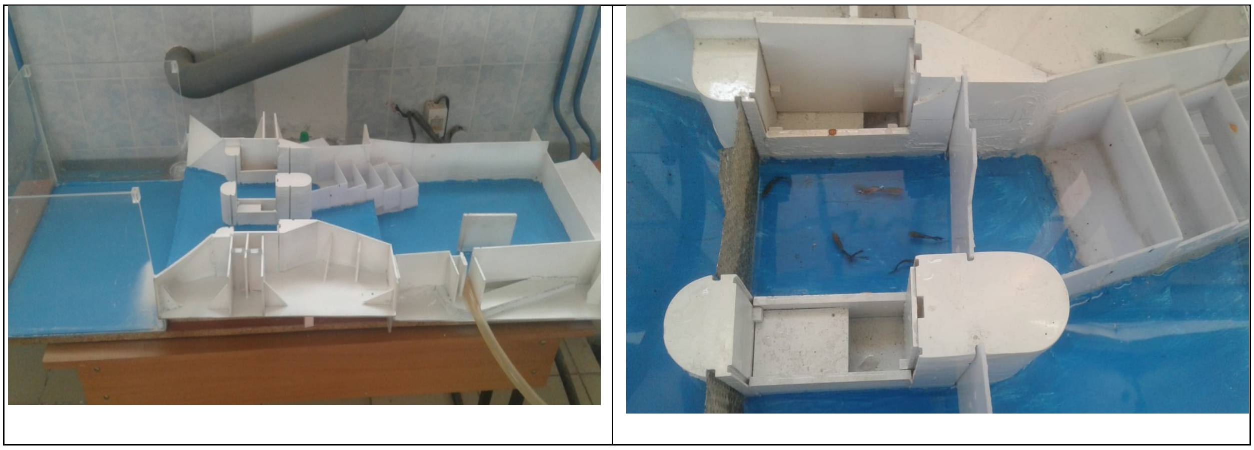

Figure 5 - Laboratory model of a fish pass 1:100.

Analytical model of the proposed technical solution. Hydraulic jets, flowing from jet-forming nozzles and interacting with each other, form a total flow. The total flow creates a zone of partially equal pressures in front of the inlet of the fish passage, which makes the passage of fish and other aquatic life into the upstream unhindered. The mathematical condition for the formation of a zone of partially equal pressures is written in the following form (Vvedensky, 2009):

$$V_{UO} = \sqrt{gH}, \quad (16)$$

where, V_{UO}- is the initial axial velocity of the total flow; g is the free fall acceleration (m/s2); H- value of the pressure attributable to the transverse dividing wall (m). The initial axial velocity of the total flow V_{UO}- itself is found by the formula:

$$V_{Uo} = \varphi \frac{V_0 \, d_{o\_n}^{\frac{2}{3}} b_э^{\frac{1}{3}} n}{9.514\,(h_э - b_э)}, \quad (17)$$

where, V(Uo) is the initial axial velocity of the total flow;

φ is a dimensionless coefficient determined empirically;

V_0 - initial velocity of hydraulic jets from jet nozzles (m/s);

d_(o_n) – diameter of jet nozzles (m);

b_e-distance between axes of hydraulic jets (m);

n - is the number of hydraulic jets in a row;

oh is the distance between the planes of propagation of hydraulic jets (m).

The value of the dimensionless coefficient depends on many factors, the main of which is the dimensions of the inlet and the configuration of the location of the jet nozzles (Vvedensky, 2009). As experimental studies show, the values of the dimensionless coefficient with a sufficient degree of accuracy for solving most practical problems vary in the range of 0.001 to 4.00. To organize the passage of fish along the fish passage of the fish pass, it is necessary to have a stable attracting flow passing through it in transit. For its formation, an additional pressure H is created, the value of which is determined from the following expression:

$$\Delta H = H - \frac{V_{Uo}^2}{g}, \quad (18)$$

where ΔH is the value of the additional pressure;

g is the free-fall acceleration (m/s2);

Thus, the additional head ΔH is the difference between the actual head H attributable to the transverse dividing wall and the heat generated by the total flow.

The value of ΔH must be set depending on the type of fish moving along the fish passage. In table. the optimal values of ΔH are presented depending on the required attracting flow, calculated according to known methods (Ko et al., 1985).

Table 3 - Optimal values of ΔH depending on the type of moving fish

Type of fish	Optimal values				Maximum values			
	attracting speed, m/s		additional head ΔH,m		carrying speed, m/s		additional head ΔH,m	
	min	max	min	max	min	max	min	max
Salmon	0.90	1.40	0.26	0.63	1.10	1.60	0.39	0.82
Sturgeons	0.70	1.20	0.16	0.46	0.90	1.40	0.26	0.63
Partial	0.50	0.80	0.08	0.20	0.90	1.20	0.26	0.46

Conclusion

The ability to use hydraulic jets to compensate for significant pressure fluctuations at the hydroelectric complex in only one inflow hole will allow the following:

– significantly reduce the length and material consumption of the fish passage;

– to ensure the possibility of a passage through the new fish passage facility – the fish passage not only for salmon but also for other migratory and semi-anadromous species of fish;

- fully link the operation of the fish pass to the features of the hydroelectric complex with the cyclic operation;

– preserve the naturalness of the conditions for the passage of migrants and fulfill environmental requirements.

The proposed changes in the design of fish passages based on the technology of hydraulic jets and their operating modes for passing fish through hydroelectric facilities make it possible to create a controlled high-speed flow regime in the fish passage, which will provide favorable conditions to the maximum extent for the passage of various types of anadromous and semi-anadromous fish through the target of the hydroelectric dam at significant fluctuations in the levels of the pools.

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