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WATER HARVESTING SWALES IN AGRICULTURE: IMPROVING RECLAMATION, EROSION CONTROL AND MOISTURE RETENTION

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Abstract. The article is devoted to the study and application of swales, simple hydraulic structures designed for water management and prevention of soil erosion. The historical roots of this technology are considered, starting from the Neolithic revolution, when small embankments were used to retain floodwaters. The article analyses the evolution of the use of swales from ancient liman irrigation systems to modern permaculture design and describes their advantages in water resources management.

Swales are shallow ditches laid along contour lines of the terrain and serve to retain surface water and promote its gradual infiltration into the soil. They prevent water erosion, contribute to moisture accumulation, improve water absorption and increase the productivity of agroecosystems. The author emphasises their particular importance for Kazakhstan, where frequent droughts and floods require effective anti-erosion measures.

The modern use of swales is also considered in the context of permaculture concepts. The article highlights the role of key permaculture figures P.A. Yeomans and B. Mollison in popularising swales and integrating them into the principles of sustainable ecosystem management. Particular attention is paid to the use of geographic information system (GIS) technologies, which make it possible to optimise the planning and implementation of swales and thus increase the effectiveness of water-management measures.

Keywords: swales; water erosion; runoff; catchment basin; GIS technologies; permaculture design.

СУ ЖИНАУҒА АРНАЛҒАН СВЕЙЛДЕРДІ АУЫЛ ШАРУАШЫЛЫҒЫНДА ҚОЛДАНУ: МЕЛИОРАЦИЯНЫ ЖАҚСАРТУ, ЭРОЗИЯНЫ БАҚЫЛАУ ЖӘНЕ ЫЛҒАЛДЫ САҚТАУ

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Аңдатпа. Мақала су ресурстарын басқару және топырақ эрозиясының алдын алу үшін қолданылатын қарапайым гидротехникалық құрылымдар, свейлдерді зерттеу мен қолдануға арналған. Бұл технологияның тарихи бастаулары неолиттік революция кезеңінен бастау алады, сол кезде тасқын суларды ұстап қалу үшін шағын бөгеттер пайдаланылған. Мақалада свейлдердің ежелгі лимандық суару жүйелерінен бастап заманауи пермакультуралық жобалауға дейінгі эволюциясы талданып, олардың су ресурстарын басқарудағы артықшылықтары сипатталады.

Свейлдер рельефтің контурлық сызықтары бойымен қазылатын таяз арықтар болып табылады және жерүсті ағын суларын ұстап, олардың топыраққа біртіндеп сіңуін қамтамасыз етеді. Олар су эрозиясының алдын алады, ылғалдың жиналуына ықпал етеді, судың сіңірілуін жақсартады және агроэкожүйелердің өнімділігін арттырады. Автор Қазақстан жағдайында олардың ерекше маңыздылығын атап өтеді, өйткені жиі болатын құрғақшылық пен су тасқындары тиімді эрозияға қарсы шараларды талап етеді.

Свейлдерді қазіргі қолдану пермакультура тұжырымдамалары аясында да қарастырылады. Мақалада свейлдерді кеңінен насихаттауда және оларды тұрақты экожүйелерді басқару қағидаттарына енгізуде пермакультураның негізгі өкілдері П.А. Йоманс пен Б. Моллисонның рөлі көрсетіледі. Сонымен қатар, свейлдерді жоспарлау мен енгізуді оңтайландыруға мүмкіндік беретін және су ресурстарын басқару шараларының тиімділігін арттыратын географиялық ақпараттық жүйелер (ГАЖ) технологияларын қолдануға ерекше назар аударылады.

Кілт сөздер: свейлдер; су эрозиясы; беткі ағын; су жинау алабы; ГАЖ технологиялары; пермакультуралық жобалау.

СБОР ВОДЫ С ПОМОЩЬЮ СВЕЙЛОВ В СЕЛЬСКОМ ХОЗЯЙСТВЕ: УЛУЧШЕНИЕ МЕЛИОРАЦИИ, КОНТРОЛЬ ЭРОЗИИ И СОХРАНЕНИЕ ВЛАГИ

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Аннотация. Статья посвящена исследованию и применению свейлов, простых гидротехнических сооружений, предназначенных для управления водными ресурсами и предотвращения эрозии почв. Рассматриваются исторические корни данной технологии, начиная с неолитической революции, когда небольшие насыпи использовались для удержания паводковых вод. В статье анализируется эволюция использования свейлов от древних лиманных оросительных систем до современного пермакультурного проектирования, а также описываются их преимущества в управлении водными ресурсами.

Свейлы представляют собой неглубокие канавы, проложенные по контурным линиям рельефа, и служат для удержания поверхностных вод и обеспечения их постепенной инфильтрации в почву. Они предотвращают водную эрозию, способствуют накоплению влаги, улучшают водопоглощение и повышают продуктивность агроэкосистем. Автор подчеркивает их особую значимость для Казахстана, где частые засухи и наводнения требуют эффективных противоэрозионных мер.

Современное применение свейлов также рассматривается в контексте концепций пермакультуры. В статье освещается роль ключевых представителей пермакультуры П.А. Йоманса и Б. Моллисона в популяризации свейлов и их интеграции в принципы устойчивого управления экосистемами. Особое внимание уделяется использованию технологий географических информационных систем (ГИС), которые позволяют оптимизировать планирование и внедрение свейлов, тем самым повышая эффективность водохозяйственных мероприятий.

Ключевые слова: свейлы; водная эрозия; поверхностный сток; водосборный бассейн; ГИС-технологии; пермакультурное проектирование.

Introduction. The water resources of the Republic of Kazakhstan are characterised by a high variability of seasonal runoff in internal catchment basins, which with high frequency leads to natural disasters such as droughts and floods (Alimkulov et.al., 2021: 59-71). The frequency of severe droughts in Central and Western Kazakhstan is once every 4–6 years, and in the regions of Eastern and Northern Kazakhstan once every 8–45 years (Kozhakhmetov, 2016: 7-19)

Between 2005 and 2015, more than 300 floods of various origins were recorded in Kazakhstan, of which 70% were associated with spring high water, 30% were caused by rainfall and 10% by other factors. Floods occur in Kazakhstan every year, but their distribution and scale vary greatly from year to year, and catastrophic floods on Kazakh rivers occur approximately once every 50–100 years (Ramazanova, 2015: 103-105).

This article examines the importance of simple hydraulic structures, the so-called swales (embankment-ditch systems, swales), in minimising losses from droughts, floods and soil erosion and in increasing ecosystem productivity.

History of swale use. Archaeological research has shown that people have been using the swale technology since the Neolithic revolution. According to G.N. Lisitsina, the first stage in the history of the emergence and development of irrigated agriculture was characterised by the appearance of liman-type irrigated farming based on natural floods in the lower reaches of mountain streams or in the zones of dying-out deltaic channels of lowland rivers. Floodwaters were retained by small embankments bordering the fields. Already at that time, the first forms of land-reclamation works emerged, expressed in the cleaning of silted deltaic channels and the diversion of excess water to lower areas away from the fields. These measures not only made it possible to use flood flows rationally, but also to gradually expand irrigated areas; this first stage covered the period from the 5th millennium to the beginning of the 1st millennium BC (Lisitsina, 1965: 169).

Today, swales are a key element of modern landscape design and water-resources management. These engineering structures are intended to retain and distribute snowmelt and rainwater runoff, improve soil water infiltration and prevent erosion. Swales are shallow ditches located along contour lines of a site; their main task is to intercept and retain local runoff to ensure its gradual infiltration into the soil. In agriculture, swales are used to improve the soil water regime, increase yields and reduce erosion; they enable efficient distribution of snowmelt and rainwater, prevent the formation of erosion gullies and create favourable conditions for plant growth (Permaculture Fandom, 2024).

Structures and devices of independent use include infiltration ditches with embankments, water-regulating (drainage) embankments on slopes, embankments with a wide base (embankment-terraces), water-retaining embankments at gully heads, various flow-dispersing devices and headwater and bed structures (Petel'ko, 2016: 242-245).

Modern swales as a concept of water-resources management and erosion control began to develop in the mid-20th century. Important milestones in the history of swales include:

- 1950s: Australian farmer and inventor P.A. Yeomans introduced the "Keyline Design" concept, which uses contour ploughing and swales to reduce loss of topsoil through water erosion, improve the water regime and increase soil fertility (Yeomans, 1954).
- 1970s: Australian ecologist and designer B. Mollison together with D. Holmgren developed the principles of permaculture, which include the use of swales to create sustainable agroecosystems (Mollison, 1981).

Today, swales are promoted by various organisations, permaculture designers and ecologists worldwide. Key figures in permaculture design include: G. Lawton, a well-known permaculture designer and trainer actively promoting the use of swales in his projects worldwide; the Permaculture Research Institute, founded by B. Mollison and G. Lawton, which is engaged in education and promotion of permaculture, including swale application (Permaculture Research Institute, 2024); specialists in ecological design such as M. Shepard and D. Doherty, who actively use swales in their sustainable-landscape projects (Shepard, 2013: 330); and S. Holzer, a farmer and international consultant on ecological agriculture known as "Holzer permaculture" (Хольцер, 2012: 344).

Swales for soil-moisture conservation. Swales are used not only by innovators in permaculture design; in routine agricultural practice they also occupy a worthy place. Swales are used to increase water infiltration into the soil, thereby improving the water balance by replenishing groundwater reserves and reducing the need for additional irrigation;

A special case of swales is embankment-terraces with a wide base, which are laid they are widely used as elements of limans under liman irrigation (Gostishchev, 2011). Out on land-use slopes with a surface gradient of no more than 5°. Their parameters are: total height 0.3–0.6 m, base width 2.7–5.4 m, wet slope ratio 1:5 and dry slope ratio 1:4. Embankment-terraces are constructed parallel both to contour lines of the terrain and to each other, and under conditions of excessive moisture and low filtration coefficient they are sometimes oriented at an angle to the contours. At the ends of terraces built along contours, buttresses turned upslope at 120° are arranged, as well as earth bunds every 200–300 m.

These simple hydraulic structures prevent soil wash, promote the conversion of surface runoff into subsurface flow and thus increase crop yields; soil tillage is then carried out along the direction of the embankments. The design of embankment-terraces and the spacing between them is performed using specific formulas, the main goal being to set embankment parameters that ensure complete retention of surface runoff within the terraced area, using a contour land-use plan with clearly defined boundaries and areas with uniform slope.

Embankment-terraces are constructed with ploughs, bulldozers and graders; embankments up to 0.5 m high are formed using standard ploughs by throwing soil from both sides, whereas higher embankments are built with bulldozers and graders. Construction involves the following technological operations: clearing slopes and filling small gullies and rills; setting out terrace lines on the slope; removing the topsoil and loosening the foundation for the embankment, pond, bunds and buttresses; layering and compacting the soil with allowance for potential settlement; arranging bypass channels at the ends of buttresses; and covering embankments, bunds and buttresses with a thin layer (5–10 cm) of topsoil followed by seeding.

To ensure proper functioning of embankment-terraces and prevent their erosion, it is necessary to carry out regular inspections and promptly repair any damage.

Water-retaining embankments with a wide crest are created to retain runoff from the catchment area and to stop gully growth; they are placed on land adjacent to the gully, above its head. A water-retaining embankment consists of an earth fill and an excavation from which the soil used for fill is taken. On loess and loess-like loams, embankments generally have the following dimensions: crest width 2.5 m, base width 7.8 m, total height 1.5 m, working height 1.0 m, wet slope ratio 1:2 and dry slope ratio 1:1.5.

When planning embankments, their axes are oriented parallel to contour lines and buttresses are installed at 100–120° to the axis to more effectively retain surface runoff; the buttresses may be closed or open with spillways for draining excess water. To improve runoff retention, bunds 2.5 m wide are placed at right angles to the axis every 30–50 m. The crest of the embankment and the crest of the buttresses are made strictly horizontal to prevent breaches and structural failure.

The length of embankments at gully heads is determined considering the terrain, width of runoff and other site features, and usually does not exceed 400–500 m; the first embankment from the gully head is placed at a distance of no more than three gully depths.

The construction technology of water-retaining embankments includes a number of technological operations that ensure reliable bonding of the structure with the native soil and compliance with all hydrological and construction calculations. Initially, the area of the future structure is ploughed to a depth of 25–27 cm. Then the vegetation layer is removed from the foundation of the embankment and future pond by bulldozer and temporarily moved upslope. After preparing the foundation, the soil extraction area is loosened; the loosened soil is moved by bulldozer or scraper and used to form the embankment. For maximum compaction, soil is placed in 40–50 cm layers and each layer is compacted by tractor passes with a water-filled roller; levelling of the horizontal crest surface is done with a bulldozer and the quality of works is checked with a level. The previously removed topsoil is spread over the excavation in front of the embankment and over the embankment body during its stabilisation; sod is laid in water-bypass and water-conveyance channels, and perennial grasses are sown on the embankment, bunds and buttresses.

Compliance with the technology for creating water-retaining embankments and with periodic inspections ensures their long-term operation and effective anti-erosion performance; if damage or destruction occurs, repairs are performed, and when more than 30% of pond capacity is silted, urgent cleaning is required (Apazhev et al., 2024: 78-87).

The combination of swales and shelterbelts provides a synergistic effect. Water-regulating shelterbelts arranged across slopes, combined with simple hydraulic devices – embankments along the lower tree line with bunds, deep (0.6–2.0 m) slit drains, intermittent trenches and pits between rows – increase water-infiltration effect by 2–3 times and anti-erosion effect by 3–5 times (Panov, 2021: 6-18).

Hydraulic anti-erosion measures on arable land (embankment-terraces, diversion embankments and furrows) are highly effective: they reduce runoff depth by 30–50 mm and soil loss by 8–12 times. Infiltration in runoff-regulating shelterbelts can further be increased by combining them with practices that reduce soil freezing and increase flooded area (infiltration surface) due to ponding of water coming from fields, such as mulching the soil in the inter-rows and combining shelterbelts with ditches and embankments; this increases water absorption in shelterbelts several-fold to 3000–5000 mm, and total water infiltration over the catchment can reach 40–50 mm (Barabanov, 2023: 36–46).

Methods for enhancing water infiltration in shelterbelts are conventionally divided into biological (mulching), hydraulic (embankments, ditches, slits with filter fill etc.), hydromeliorative (drainage–irrigation systems on afforested fields) and complex (biological, hydrological and hydromeliorative) measures. If average water infiltration in runoff-regulating shelterbelts is 400–600 mm, then with infiltration-enhancing measures it increases several-fold and can reach 1500–2000 mm and more on soils with low infiltration capacity (Barabanov, 2018: 23-30).

Long-term observations (1978–2018) have established the high anti-erosion efficiency of swales combined with shelterbelts. The runoff-regulating role and service life of swales depend on their position within the shelterbelt and on the presence of soil-protection agronomic practices in the catchment, including contour-strip cropping patterns, special techniques such as micro-limans, pits and intermittent furrows on fallow, slotting and mole-drainage in winter crops and perennial grasses. These measures ensure retention of snowmelt runoff 50–60 mm deep and regulate soil loss to controlled levels of 0.3–1.0 t/ha per year; exclusion of contour-strip cropping and special agronomic measures markedly reduces the anti-erosion effectiveness of the bioengineering complex (Poluektov, 2020) (Vol’nov, 2017: 42-48).

Swales as a tool for controlling soil erosion. Swales are successfully used to combat soil erosion. In the Republic of Kazakhstan, soil erosion, along with soil dehumification, is the most widespread type of land degradation and causes significant economic and environmental damage, threatening soil as both a key means of agricultural production and an independent biosphere component (Vol’nov, 2017: 42-48).

Water erosion is the most widespread and damaging type of soil degradation due to its broad geographical distribution and the depth and irreversibility of changes in soil cover; it is one of the most powerful modern relief-forming processes, transporting enormous masses of material on cultivated land, acting as a major source of environmental pollution and being among the primary causes of siltation of small rivers and degradation of agro-landscapes (Manaenkov, 2015: 65-68).

According to the Center for Environmental Monitoring (New York, USA), at current rates of erosion and deforestation by 2030 the area of fertile soil on the planet will decrease by 950 billion tonnes and forests by 460 million hectares; if in 2020 an average of 0.27 ha of fertile soil per capita was available, by 2030 this will shrink to 0.18 ha. Soil loss from 1 ha per year reaches 2–5 m^3 on slopes of 1–2°, often 10–20 m^3; on slopes of 4–6° it is 30–40 m^3 and sometimes exceeds 80 m^3 per year. Erosive runoff carries away 50–75% of snowmelt water from fields, which sharply reduces soil moisture and yields; yield losses on heavily eroded soils reach 60%, and on moderately eroded soils 30–40%. Simultaneously, deep rills and gullies form, draining adjacent arable land and worsening conditions for transport and agricultural machinery; eroded material carried through gullies and ravines clogs or completely buries valuable floodplain meadows and arable land and silts rivers, ponds and reservoirs; without anti-erosion measures, erosion develops at an accelerating pace (Suchkov, 2020: 56-61).

Runoff retention and redistribution prevent erosional processes and improve soil structure. Long-term studies are presented on the influence of an anti-erosion complex on chernozem soils consisting of a narrow two-row shelterbelt with a ditch in the inter-row and an embankment along the lower edge, plus an embankment-terrace, in reducing spring runoff and nutrient export to the hydrological network. Depending on the composition of the anti-erosion complex and the agronomic background, snow-cover height and total water storage in snow were always higher and in some years reached up to 100% above the control, while runoff from treated catchments was always lower and decreased by 26–78%, reducing soil loss by 58–97%. In years without soil loss, nutrient export from catchments with the most saturated anti-erosion complex (shelterbelt with ditch and embankment plus embankment-terrace) was lower than in the control and decreased by up to 87%; in years with noticeable soil loss, nutrient export decreased by 69% in the shelterbelt-plus-swale variant and by 58% in the shelterbelt with swale plus embankment-terrace variant (Podlesnykh, 2019: 14-17).

Water-retaining embankments built at the heads of active gullies in the lower slope sections not only stopped further gully growth but practically retained all snowmelt runoff from the catchment in a pond in front of the embankment, transforming it into soil moisture; fine material eroded from the catchment accumulated near the pond (Karpovich, 2012: 114-118).

Use of swales to increase yields. Anti-erosion complexes on sloping land in the form of shelterbelts and embankment-terraces increase yields of winter wheat and barley by 0.38–0.73 t/ha, perennial grasses by 4.50 t/ha, field pea by 0.32–0.45 t/ha and buckwheat by 0.14–0.44 t/ha compared with areas without anti-erosion elements. The greatest yield effects are observed in years with insufficient precipitation during the growing season (Tarasov, 2021: 59-63).

Design parameters of the simplest hydraulic structure, the ditch-embankment, used in calculating the volume and mass of sediment are: ditch depth 0.6 m, ditch width at the top 1.5 m, at the bottom 0.5 m, slope ratio about 1:1, embankment height above the ditch crest 0.6 m, water-holding capacity of the ditch itself about 0.5 m³ per metre plus 1.5 m³ per metre for ponding in front of the embankment, with a total capacity of about 2 m³ per linear metre. A 100-m-long protective shelterbelt can retain a single surface runoff event of up to 200 m³ including sediment. Studies of complexes consisting of simple anti-erosion hydraulic structures – ditch-embankments in the inter-rows of protective shelterbelts – show that they can reduce soil erosion and accumulate sediment in the ditch and in front of the embankment in amounts of 0.84 t per metre at 2–3° slope and up to 1.74 t per metre at 5–6° slopes (Balakai, 2024: 80-99).

Application of GIS technologies for the design and optimisation of swales. The development of computer technologies and widespread access to global positioning and geographic information systems has led to a new concept known as "precision agriculture" or "site-specific agriculture". Geoinformation technologies are a set of techniques, methods and tools for using hardware and software for the processing and transmission of information that enable the functional capabilities of GIS. These technologies integrate remote sensing of the Earth (RSE), database management systems (DBMS), GPS, methods of geoinformation analysis and interpretation, internet technologies, cartographic systems and digital-image processing; they are used to produce thematic farm maps (land use, slope and aspect, soil types and properties, agrochemical data, crop condition, yield etc.) (Fedorenko, 2019: 316).

It seems advisable to use GIS technologies to ensure rapid construction of swales because modern GIS not only significantly reduce design and construction time but also increase the scale of implementation. Using GIS, it is possible to quickly analyse topographic data, identify optimal sites for swales, predict their effectiveness and coordinate construction works, which opens up wide opportunities for mass adoption of swale technology, increasing the effectiveness of water-management measures and improving the condition of agricultural land in the shortest possible time.

At present, GIS are generally used only for graphical presentation of projects, which does not fully exploit their potential. Using GIS for shelterbelt design makes it possible to accurately calculate their location considering runoff and relief characteristics and substantially shorten design time.

As a calculation framework for designing shelterbelts and hydraulic structures in a GIS environment, a method developed for the Central Black Earth economic region was used, according to which runoff can be calculated by the formula:

$$W_v = h \cdot P \cdot K_e \cdot E \cdot R \cdot K_s \tag{1}$$

where W_v is spring runoff, mm; h is zonal mean multi-year snowmelt runoff from bare fallow or compacted arable land, mm; P is a correction for soil type (subtype); K_e is a coefficient describing the effect of erosion degree (non-eroded and slightly eroded, 0.94; moderately eroded, 1.0; severely eroded, 1.1); E is a coefficient accounting for slope exposure (north, 1.25; south, 0.75; north-west and north-east, 1.12; south-west and south-east, 0.88; west and east, 1.0); R is an ordinate of the probability curve used to convert mean multi-year runoff from maps to runoff with 10% probability (i.e. a runoff amount that occurs on average once in 10 years or more); K_s is a coefficient of runoff reduction by soil-protection agronomic or hydromeliorative measures.

GIS capabilities make it possible, using this relationship, to convert runoff depth in millimetres into cumulative runoff volume in cubic metres and to calculate it for an entire catchment. Based on a raster grid of runoff volume built automatically in GIS using a digital elevation model, and a grid of flow-line lengths, shelterbelts can be designed; when the position of the shelterbelt is changed, GIS automatically recalculates runoff volume in the inter-belt space, allowing determination of the most effective spacing from the standpoint of runoff and soil loss. Depending on runoff volume, slope length and other parameters, one or several shelterbelts may be required (Podlesnykh, 2023: 37-41).

Impact on microclimate. The creation of soil-protective shelterbelts and agro-forestry–reclamation complexes in combination with swales plays a key role in forming a favourable microclimate in agricultural areas. Swales are rarely used alone; they normally serve as water-supply structures for shelterbelts, and their synergistic interaction greatly enhances moisture retention, reduces soil erosion and improves agro-physical and agro-chemical soil properties.

From the standpoint of reducing soil wash, the most effective anti-erosion territorial organisation is the agro-forestry–reclamation variant. At first glance it is the most expensive because it requires planting two narrow two-row shelterbelts with an embankment along the lower edge and a ditch in the inter-row along contour lines, perpendicular to runoff lines – an arrangement most effective in minimising erosion–hydrological processes. However, due to a 70% reduction in average multi-year soil loss, reduced energy-intensive tillage operations, more even snow distribution and conversion of surface runoff into soil moisture, yields of cereals increase (Solov'eva, 2019: 50-59).

According to SP 100.13330.2016, a reclamation system is a set of interconnected hydraulic and other structures and devices, including land plots within the rights-of-way of the reclamation system or hydraulic structure, that ensure favourable water, air and thermal regimes of soils and microclimate on reclaimed lands (Ivonin, 2022: 119-140).

Experience in agro-forestry reclamation has clearly shown that establishing a system of protective forest plantations combined with other environment- and soil-improving practices in open steppe has beneficial environmental effects, optimises agro-physical and agro-chemical soil properties, increases accumulation of crop residues compared to open steppe and enhances biocenotic potential. Research shows that shelterbelts significantly improve microclimate: 130 years of data indicate that in fields protected by shelterbelts, the seasonal groundwater level is optimised, wind speed decreases by 30–35% and snow accumulation increases by 25–30%, preventing deep soil freezing and rapid snowmelt (Turusov, 2024: 92-95).

The positive effect of soil-protective agro-forestry–landscape complexes on crop productivity can be explained by the formation of a favourable microclimate for plant growth and development in the inter-belt space, as well as by the input of crop residues into the soil as the main source of replenishing soil carbon stocks; the greatest differences among catchment variants were observed in buckwheat, where yield was 12.8% (2.21 centners/ha) higher than in the control (Podlesnykh, 2023: 37-41).

Regulators of self-organisation of the agro-forestry–reclamation supersystem in farming regions are the proportions of arable land, hayfields, pastures, forests and open water surface. Arable land destabilises the self-organisation of the reclamation supersystem, whereas hayfields, pastures and forests stabilise it; open water surfaces affect self-organisation through internal water cycling in agro-landscapes, increasing relative air humidity and altering other microclimate characteristics and groundwater dynamics (Ivonin, 2023: 62-75).

There is a need to develop systems for adaptive-landscape agro-forestry–reclamation planning of arable lands. Agro-forestry reclamation measures for protecting soil from wind and water erosion and improving microclimate involve the creation of a system of forest plantations; such a system of protective forest plantations is defined as an interconnected set of shelterbelts and small forest blocks, rationally distributed across landholdings considering relief and soil conditions (Abduğaniev, 2023: 422-428).

Conclusion. The review shows that swales are not only historically significant but also a modern tool for water-resources management. Their effectiveness and versatility are confirmed by long-term practical experience and contemporary research. Due to their simplicity and economic affordability, swales play a key role in addressing land degradation, water erosion, droughts and floods, especially in regions with unstable water regimes such as Kazakhstan.(1)

Historically, swale use began in the Neolithic, when they served to retain floodwaters and increase crop yields. Today their role extends beyond agriculture to landscape design, ecosystem restoration and permaculture. Modern concepts such as P.A. Yeomans' Keyline Design and the approaches of B. Mollison and D. Holmgren in permaculture demonstrate the high versatility and effectiveness of swales, and their combination with shelterbelts generates a synergistic effect that greatly enhances their functions.

Geographic information systems open new horizons for the design and management of swales, making it possible to choose optimal sites, predict system efficiency and significantly reduce time and resource costs. This underlines the importance of further integrating GIS into water-resources management practices, especially under climate change and growing agricultural demands.

In the future, it seems appropriate to develop an innovative system for creating hydraulic structures aimed at optimising the use of atmospheric-precipitation moisture in agriculture and other sectors. The central idea is to employ artificial intelligence that uses GIS data to automate the design of swales, shelterbelts, dams and ponds; the system would also automate earthworks by equipping earth-moving machinery with guidance systems that ensure accurate construction of swales along specified contour lines and of dams and ponds according to their 3D models. The proposed system opens new opportunities for sustainable water-resources management and agricultural development in Kazakhstan and beyond.

The use of GIS technologies and AI increases the accuracy and effectiveness of water-saving projects, reduces costs and enables turnkey creation of highly productive agricultural areas. Further research will improve methods for designing and implementing swales and associated hydraulic structures, ensuring their wider and more effective application in diverse landscapes and climatic conditions.

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