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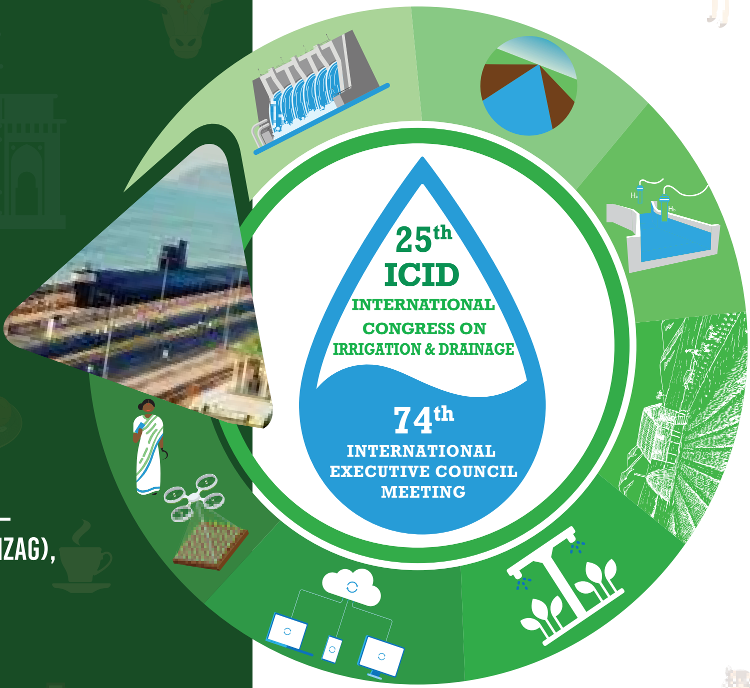

PROCEEDINGS

INTERNATIONAL WORKSHOP ON THE STATE OF DRAINAGE WORLDWIDE

TACKLING WATER SCARCITY IN AGRICULTURE

LUTTER CONTRE LA PENURIE D’EAU DANS L’AGRICULTURE

INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE
COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE

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The International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). The Commission through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over six decades. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework.

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- **B** Be a Catalyst for a Change in Policies and Practices
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- **E** Encourage Research and Support Development of Tools to Extend Innovation into Field
- **F** Facilitate Capacity Development

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CONTENTS

DESIGN STANDARDS FOR DRAINAGE AND FLOOD PROTECTION OF THE POLDERS IN THE WORLD

Bart Schultz[1]

ABSTRACT

The polders of the World are located in flood prone areas. To enable their functioning drainage and flood protection are an absolute requirement. In addition, irrigation may be needed for a proper functioning of the water management system. In total 101 countries with polders have been identified, with a total area of at least 70.2 million hectares. In relation to the situation before impoldering, three types of polders may be distinguished: impoldered low-lying lands, lands gained on the sea and drained lakes. As far as the land use is concerned, most of the polders were reclaimed for agricultural land use, but gradually more and more polders are reclaimed for urban, industrial and multiple land use, including nature conservation and recreation. In the course of time, in quite some of the polders that were reclaimed for agricultural land use, especially urbanisation is taking place.

In the paper an overview will be given of the polders in the World, as well as of the design standards for the drainage and flood protection provisions. It will be shown that different levels of safety are being applied for these provisions, as well as in the countries with polders. In addition an overview will be given of the developments that are taking place in several of the polder areas and the implications that such developments may have for the requirements for the drainage and flood protection provisions.

Keywords: Polders, Drainage, Flood protection, Design criteria.

1. INTRODUCTION

The lowlands in the World are located in the river floodplains and delta's, coastal zones, as well as in inland depressions, to a large extent in flood prone areas. In the lowlands the polders of the World are located. To enable their functioning drainage and flood protection are an absolute requirement. In addition, irrigation may be needed for a proper functioning of the water management system. In total 101 countries with polders have been identified, with a total area of at least 70.2 Mha (million hectares). In relation to the situation before impoldering, three types of polders may be distinguished: impoldered low-lying lands, lands gained on the sea and drained lakes. Most of the polders were reclaimed for agricultural land use, but gradually more and more polders have been reclaimed for urban, industrial and multiple land use, including nature conservation and recreation. In the course of time, in quite some of the polders that were reclaimed for agricultural land use, especially urbanisation is taking please.

In the paper an overview will be given of the polders in the World, as well as of the design standards for the drainage and flood protection provisions. It will be shown that different levels of safety are being applied for these provisions, and in the countries with polders. In addition an overview will be given of the developments that are taking place in several of the polder areas and the implications that such developments may have for the requirements of the drainage and flood protection provisions.

2. BACKGROUND

In a paper, published in 2003, I stated:

Lowland, flood prone areas are by their nature generally unsuitable for development. This is mainly caused by the soil conditions, waterlogging, regular, or even permanent inundation and environmental values. However, because of their general strategic location and shortage of land in densely populated countries there is in many cases an enormous **pressure to develop**

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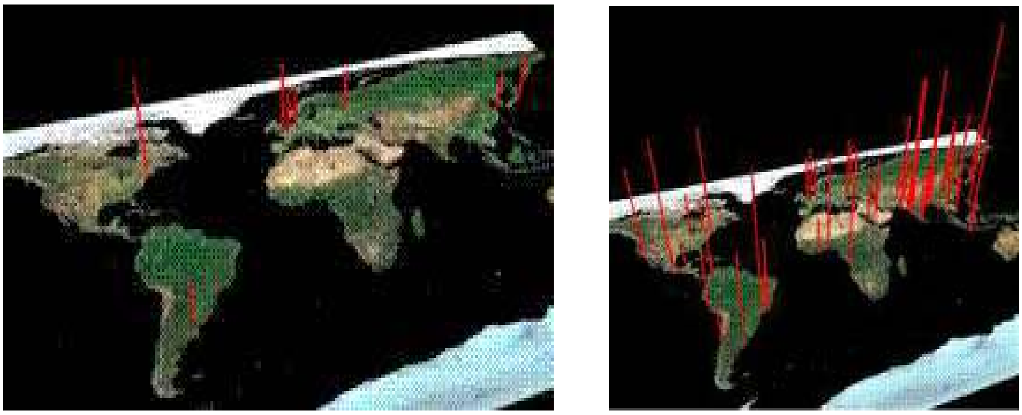
these areas (Schultz 2003).

Despite of the concern for the impacts of climate change on sea level rise, increase in peak rainfall and river floods, since the beginning of the 21st century the pressure to develop lowland areas for various types of land use has increased (Schultz 2018, 2019). This can be illustrated with the growth of cities with more than 5 million people, most of these located in coastal lowland areas (Figure 1).



(a) (b)

Figure 1. Cities with more than 5 million inhabitants in 1950 (a) and 2015 (b)
(UN Population Division 2006; Schultz 2018)

In the development of lowlands the polders play a significant role, while generally flood protection will be required to create acceptable conditions in the area to be developed. Because of the flood protection drainage with an artificial outlet will be required. These are the basic components of a polder.

3. DEFENITIONS OF POLDERS

Several definitions of polders have been given. The work presented in this paper is based on the following definitions.

Polder. A Level area which in its original state was subject to high water levels (permanently or seasonally, originating from either the surface water or ground water), but which through impoldering is separated from its surrounding hydrological regime in such a way that a certain level of independent control of its water table can be realised (after Segeren 1982).

In addition to the impoldered low-lying lands there are two other specific types of polders: the lands gained on the sea and the drained lakes. For these polders the following definitions are applicable.

Land gained on the sea. Land (polder) that was reclaimed along a coast. Before reclamation such an area felt dry during low tide and was inundated during high tide.

Drained lake. Polder that was created by the reclamation of an area that previously was permanently under water.

4. INVENTORY OF POLDERS IN THE WORLD

A first inventory of the polders in the World was published at the occasion of the symposium on *Polders in the World* that was held in Lelystad, the Netherlands 4-10 October 1982 (Group Polder Development 1982). Based on this first inventory, since 2014 a more elaborate inventory is being done in the Batavialand Museum in Lelystad, the Netherlands (Batavialand Museum web site). The, so far, identified area of polders by Continent is shown in Table 1. The location of the identified polders is shown in Figure 2. From Table 1 it can be derived that by far the largest polder area in the World (89%) is located in Asia, with the America's as a second with 15%

Table 1. Countries with polders and polder area by Continent (Batavialand web site)

Continent	Countries with polders	Area in Mha
Africa	27	1.51
America's	17	10.7
Azia	21	62.4
Europe	34	5.20
Oceania	2	0.0134
Total	101	70.2

5. Some characteristics of the polders in the World

From the collected information some specific conditions of polders can be derived. A problem is that in the literature polders are often not specifically mentioned. For example there is very old information about dikes and drainage. However, in many cases the area behind such dikes is not necessary a polder, while it may not have been separated from the surrounding hydrological regime.

From the country documents as posted on the website of the Batavialand Museum some characteristic polders in the World can be derived.

Oldest polder. Although it is very difficult to determine what could have been the oldest polder in the World, there are probably two potential locations. These are in Egypt and in Mesopotamia. In both cases it is not specified whether the area was only protected against flooding and had natural drainage, or was also separated from the surrounding hydrological regime, and therefore a polder.

In Egypt there are records of reclamation works by King Men (or Menes) who ruled Egypt around 3400 BC. He built his new capital at Memphis on the old fertile riverbed, for which according to the historian Herodotus he constructed a dam in the river Nile some 20 km south of Memphis at Kosheish. The course of the river was diverted to a canal that was excavated between two hills. The dam is supposed to have had a maximum height of 15 m and a crest length of some 450 m. In a later stage king Men excavated a lake northwest of the new town and dug a canal to connect it with the river Nile. The dam had to be guarded and maintained carefully, because in case of a breach the entire city of Memphis would have been flooded. When Herodotus visited Egypt some 2,500 years later, the dam was still guarded with greatest care by the Persians (Biswas 1972). However, this narration of Herodotus has been contested by Smith (1971), who stated that *it is incredible that around 3000 BC Egyptian civil engineering had developed to the point where a river of the size of the Nile could be dammed*.

Figure 2. Location of the identified polders in the World (Batavialand web site)

Violet (2007) describes that major floods of Euphrates River occurred in Mesopotamia and shows a description of a flooding of the city of Shuruppak that dates from the first half of the 2nd millennium BC. He also describes that around 1800 BC the code of the Babilonia King Hammurabi, in addition to the regulation of irrigation, contained the requirement that riverside inhabitants had to maintain the dikes that protected the fertile lands near the river courses.

Lowest polder. The lowest polder that has been identified is located at about 210 m-MSL (mean sea level) along the northeast bank of Lake Galileo.

Deepest polder. Not the lowest polder, but the deepest in relation to the surrounding hydrological regime is most probably the Lammefjord Polder in Denmark. This polder is located at 7.5 m-MSL at the north side of the isle of Sjaelland along a fjord in open connection with the North Sea.

Highest located polder. The highest located polder in the World is most probably the area where Mexico City is located at about 2236 m+MSL.

'Strangest polder'. The 'strangest polder' that could be identified is the Söderfjärden Polder in Finland. This polder is located at the place where at least 640 years ago a meteorite touched the earth and made a deep hole. Over the centuries the hole was filled up with sediment and now the area is cultivated in a polder (Figure 3).

Largest polder area. The country with the largest polder area is China with about 41 Mha (Zhanyu et al. 2005). The country with the largest polder area compared to its total area is most probably Bangladesh, with the Netherlands as a good second.

Figure 3. The Söderfjärden Polder in Finland (source: Google Earth)

6. design standards for drainage and flood protection provisions

With respect to the design of drainage and flood protection provisions for polders several aspects play a role like: envisaged land use, climate, soil type and regime of the outside water. As far as the land use is concerned in most cases the design standards for urban areas would have to be significantly higher than those for rural areas. For drainage systems this is primarily caused by the fact that in urban areas the period between precipitation and the resulting discharge is much shorter than in rural areas. Another important reason is that the value of public and private property per unit area in urban areas is many times higher than in rural areas (Schultz, 2012). Therefore, due to the rapid urbanisation, especially in emerging countries increasingly problems occur to achieve an adequate overall water management where the interests of both the urban and rural community are being served at an adequate level of service. As far as agriculture is concerned a distinction can be made in rice polders and dry food crop polders. The soil type, especially the distinction between clay and peat soils in rural areas, plays an important role in the selection of the field systems. As far as the outside water is concerned a distinction can be made between canals, lakes, rivers and the sea.

6.1. Design standards for drainage

Design standards for drainage systems in flat, flood prone coastal and deltaic areas have been summarised by Schultz (2019). The same standards are basically applicable to polders, and are:

- *preferred normal conditions*. These are the conditions one would like to maintain in the area. They result in a preferred water level, or water levels and operation rules for the discharge structures, like outlet sluices, or pumping stations;
- *design conditions*. These are the conditions on which the designs of the drainage systems are based. In general these conditions are formulated as:
  - * exceedance of the preferred water level(s);
  - * duration of the exceedance;
  - * the chance per year for which the prescribed exceedance can occur;
- *extreme conditions*. Although this is generally not a design criterion, control computations can be made for extreme situations. In these situations bankfull storage in the drains is generally considered. When the results are considered unacceptable, the design criteria would have to be modified.

Important for drainage systems in polders is the relation between water storage and pumping capacity, for which an optimum needs to be determined. The storage is determined by the percentage of open water and the polder water level below surface. As an example values for different types of polders in the Netherlands are shown in Table 2.

Table 2. Design standards for drainage systems in polder areas in the Netherlands (Luijendijk and Schultz 1982)

Soil.landuse	Percentage of open water	Water level in m below surface	Pumping capacity in mm/day
Peat polder	3 – 10	0,20 – 0,50	8 – 12
Old clay polder			
• meadow	3 – 10	0,40 – 0,70	8 – 12
• arable land	5 – 10	0,80 – 1,00	8 – 12
IJsselmeerpolders	1 – 2	1,40 – 1,50	11 – 14
Urban polder	3 – 8	1,50 – 1,80	15 – 30
Greenhouse polder	3 – 10	0,80 – 1,00	20 – 30

Design standards of various countries are difficult to obtain. In Table 3 the data of several polders are shown.

Table 3. Design standards for identified drainage systems in polders (Batavialand Museum, web site)

Type of polder	Percentage of open water	Water level in m below surface	Pumping capacity in mm/day
Bolivar coast polders, Venezuela			12-17
Chang Chien Polder, China			100
Chiang Rak Klongdarn, Thailand			46
Coastal polders, Bangladesh			22
Hachirogata Polder, Japan			225
Leziria Grande de Vila Franca de Vira, Portugal			13.2
Holland Marsh, Canada	> 3	1.2	25-30
Nile Delta, Egypt			8
Pardina Polder, Romania			7.3
Pego-Oliva Polder, Spain			60
Pluit Polder, Indonesia			56
Polders along Danube, Romania			5.2-6
Polders in the Fens, England			4.3-19
RUT Irrigation District, Colombia			6,8
South Taiwan Science Park, Taiwan			2000

Wageningen polder, Surinam			20

6.2. Design standards for flood protection

Measures in the field of flood management and flood protection would generally have to be designed at a much higher level of safety than measures for drainage, while the number of dead and displaced people, and damage due to flooding may be much higher than in case of inundation due to exceedance of the discharge capacity of drainage systems. Also in this case a distinction would have to be made among urban and rural areas, although this is not always possible in densely populated regions. In such cases the measures would have to be based on the urban requirements. With respect to actual measures for flood management and flood protection distinction is made between structural and non-structural measures (ICID Working Group on Non-structural Aspects of Flood Management, 1999; Van Duivendijk, 2005).

The flood damage in rural areas will primarily be reduction in yield of crops and in the coastal areas the risk of flooding with saline water. The design standards would have to be such that these risks are reduced to an acceptable level, which will normally be in the order of magnitude of a chance of occurrence of 5 to 10% per year. For urban areas, with exception of the flood protection provisions in the Netherlands, actual levels are generally between 0.5 to 5% per year (Table 4). Due to the rapid urbanisation in polders in emerging countries these levels are generally far below the economic optimum. In such cases there is a serious risk of loss of a large number of human lives, an enormous displacement of people and huge damage when really an extreme event would occur. The too low level of flood protection even still occurs in several of the developed countries. For example the flood protection provisions that were implemented after the hurricane Katrina flooding in the area of New Orleans have only a level of safety with a chance of occurrence of 1% per year. This implies that when a hurricane of the same magnitude as Katrina - which was about 3.5 out of a range of 5 classes - would hit New Orleans flooding can be again the result.

Table 4. Design standards for flood protection (updated after Schultz 2018)

City/country		**Risk of failure (%/year)**
Dhaka, Bangladesh		2
USA and UK (including New Orleans after Katrina)		1
India:	cities, industry	1
	rural area	4
China:	large cities	0.5
	cities	1
	rural area	5
British Columbia, Canada		0.5
The Netherlands		
	western part	0.01-0.025
	ransition area	0.05
	river area	0.08

7. LONG TERM EFFECTS

The long term effects that may have a significant impact on the design standards for drainage and flood protection in polder areas are especially the impacts of climate change, land subsidence and the impact of human activities.

Climate change.

Climate change may have impacts on sea level rise, change in river regimes and peak discharges, increase in annual and extreme rainfall. The worst forecast of sea level rise by the Intergovernmental Panel on Climate Change (IPCC) (2021) is about 1 centimeter per year. Changes in river regimes due climate change may result in more extreme peak discharges. To what extent is difficult to quantify. Increase in extreme rainfall can roughly be estimated at 10 – 45% per century.

Subsidence

Due to the temperate climate conditions and adapted water management measures land subsidence in peat polders in the temperate humid zone is nowadays approximately 10 mm/year. In the Netherlands, due to the continuously required drainage since the impoldering these lands have subsided in total 4 to 5 metres, which amounts to an average of 0.4 to 0.5 metres per century (Schultz, 2023).

In the great majority of the polders in the world there is substantially larger subsidence. In extreme cases - reclamation of peat soils in the humid tropics - areas experience subsidence of 100 to 150 mm/year. In urban areas - mainly by groundwater extraction from deeper layers - the subsidence can be up to up to 200 mm/year. Subsidence data for recent decades for various relevant locations are shown in Table 5. In case of 100 mm/year, the impact of the highest forecast by the IPCC (2021) of 1 metre sea level rise over a century occurs in about *ten years* due to the subsidence (Figure 4).

Table 5. Subsidence data for recent decades for various relevant locations (updated after Schultz 2019)

Location	Subsidence in cm/year
Tokyo	1 - 24
Jakarta, Semarang and Surabaya	0.5 – 20
Southwestern Taiwan	3 - 17
Bangkok, Taishi	4 - 12
Tianjin	3 - 11
San Francisco Bay area and Bolivar Coast Polders	0.2 - 10
Yuanchang	6 - 8
Houston-Galveston and Ho Chi Minh City	4 - 5
Manila, New Orleans, Shanghai, Ganges Brahmaputra Delta	2 – 4
Mekong Delta, Venice, Yangon	1 – 4
Mississippi Delta	0 – 3.5

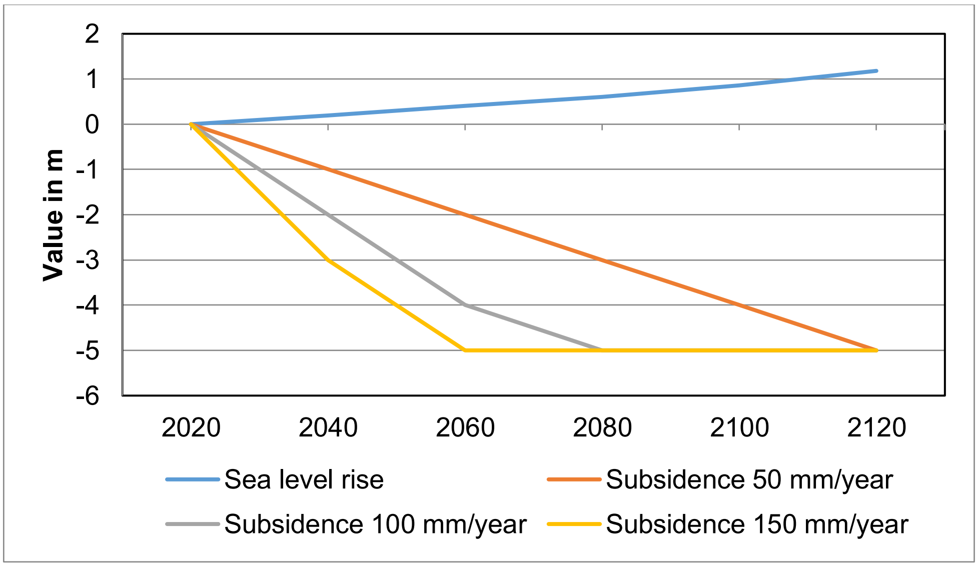


Figure 4. Sea level rise and subsidence, based on the highest forecast of the Intergovernmental Panel of Climate Change (2021) and expected subsidence and oxidation in the humid tropics. For subsidence and oxidation of peat (100 - 150 mm/year) the maximum has been set at 5.00 m, while it may be supposed that by that time the land will be under water. However, in urban areas (5 - 10 cm/year) even more subsidence can occur (updated after Schultz 2019)

Effects of human activity

In most of the polder areas the effects of human activity with respect to increase in value of private and public property, population growth and increase in value of crops is expected to be in the order of magnitude of 100 – 1,000% per century and therefore also much more significant than the impact of climate change (Schultz 2019).

The effect that the increase in value of property may have on design standards for flood protection is indicated in Figure 5 (after Schultz, 2001). This figure in essence shows that when the value of property in an area is increasing the damage due to flooding will increase proportionately. As a result the optimal level of safety would have to increase as well, in this theoretical example from a chance of occurrence of about 4% per year in 2020 to a chance of occurrence of 0.1% per year in 2070. At these chances of occurrence the total of costs for flood protection and damage are minimal. This would mean significant investment in flood protection just to maintain the economic optimal level. In this example the increase in the number of people in the flood-prone area has not yet even been taken into account.

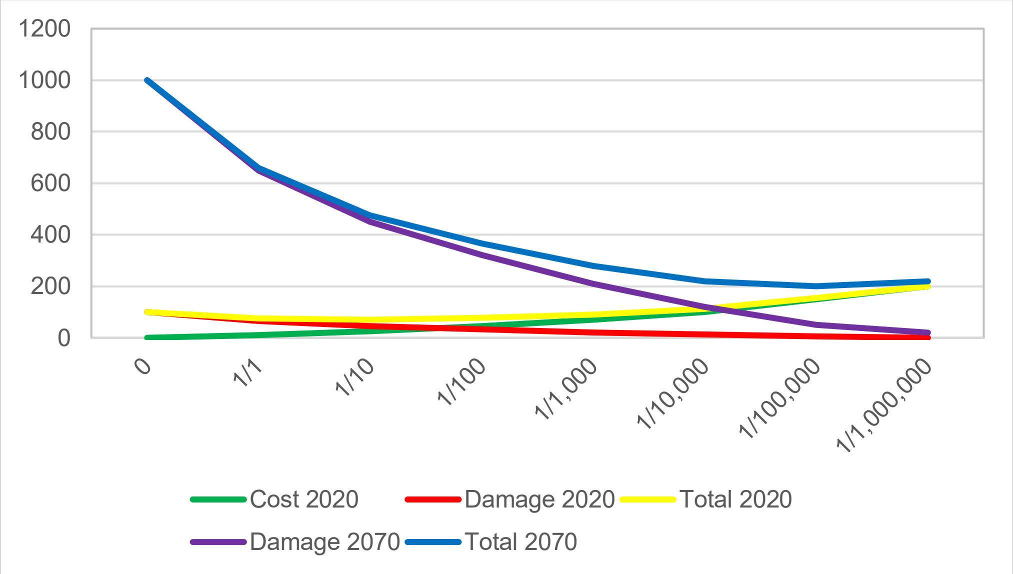


Figure 5. Interactions between design frequency for flood protection, costs and damage (after Schultz 2001)

8. CONCLUDING REMARKS

In this paper an overview has been given of the polders in the World, as well as of the design standards for the drainage and flood protection provisions, as far as they could be identified. It has been tried to show de relevant developments as well as the impacts that these developments may have for drainage and flood protection provisions. Permanent devoted operation, maintenance and upgrading will be required to keep the living conditions in the polders up to standard.

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AN INTRODUCTION TO GEOSYNTHETIC CEMENTITIOUS COMPOSITE MATS – A NEW APPROACH TO LINING OF DRAINAGE CANALS.

Simon Lester[1] and William Crawford[2]

ABSTRACT

A new class of geosynthetic has recently emerged known as GCCMs (Geosynthetic Cementitious Composite Mats) defined by the ASTM D-35 committee in 2017 as 'a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened'.

GCCMs consist of a three-dimensional fibre structure filled with a dry cement/concrete mix, overlain by a hydrophilic filter layer and underlain by a watertight membrane, which is typically a polymeric film. The material is delivered in its dry format and unrolled into place using similar installation techniques to traditional geosynthetics. Once in place, it is hydrated by spraying with water and the cement/concrete mix hardens. The result is a watertight polymeric film which is overlain by a protective fibre-reinforced concrete layer.

GCCMs have been in use since 2009 and are predominantly used for the lining of water channels for small scale drainage. More recently a variant of GCCMs has emerged which integrates a geomembrane liner onto the rear surface which allows the joints to be thermally welded. These are known as Geosynthetic Cementitious Composite Barriers (GCCBs).

Fig 1. Atfih, Egypt Type II GCCM canal lining trial at completion

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A common problem associated with canals, is seepage and erosion. Seepage can result directly in water loss through the network or result in waterlogging of adjacent land. In the case of land used for cultivation, waterlogging can reduce crop yields or cause salinization of the soils. This does not only occur in earthen canals, but also in concrete lined canals, particularly those that have experienced cracking, scour, panel separation or damage. It is also a common misconception that concrete lining of canals is an effective method of mitigating seepage losses.

The 10-year study performed by the USBR indicates that concrete over geomembrane has a 95% effectiveness at reducing seepage through canals[1]. This abstract introduces a revolutionary new class of materials called Geosynthetic Cementitious Composite Mats (GCCM's), specifically Type II GCCM's to ASTM D8364 for lining of bulk water transportation canals. The Type II GCCM in question consists of concrete encapsulated by between two geotextile layers with a minimum 1mm thick LLDPE geomembrane backing which can be thermally welded to produce a testable and low permeability joint, per ASTM D5820, with air channel testing to ensure a leak free installation. Because it is a composite of concrete and geomembrane in a single application, installation can occur as a one-step process imparting both cost and time savings to the project. The abrasion resistance of the concrete layer is 3.5 times that of typical 20Mpa concrete typically used for canal applications. With a design life of more than 50 years, this new product classification will provide a feasible, long-term solution to help preserve and protect drainage infrastructure whilst mitigating erosion and waterlogging of adjacent lands.

1. INTRODUCTION

This paper introduces a revolutionary new material technology known as GCCMs (Geosynthetic Cementitious Composite Mats) defined by the ASTM D-35 committee in 2017 as 'a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened'.

GCCMs have been developed specifically for the lining of bulk water infrastructure like irrigation canals. GCCMs are a flexible geosynthetic fabric, filled with a dry concrete powder mix, that hardens on hydration to form a thin, durable, waterproof concrete layer. GCCMs allow concrete covered geomembrane installation without the need for conventional concrete plant or mixing equipment while also reducing vehicle movements and contractor burden.

GCCMs are comprised of geosynthetic components to create a three-dimensional structure that encapsulate a specially formulated dry concrete mix with a polymeric geomembrane backing providing very low permeability. GCCMs can be hydrated either by spraying or by being fully immersed in water and are typically used for erosion control or containment applications.

Fig 2. Example of a Type II GCCM manufactured by Concrete Canvas Ltd - CCX-M™

The layers act to contain the cementitious blend during transport and installation, ensuring a consistent density of cement throughout the material and control of the water: cement ratio on hydration. Properly manufactured GCCMs cannot be over hydrated as they will fully set underwater, which greatly facilitates hydration on site by removing the need for careful water: cement ratio control. ASTM D8030-16 specifies the practice to prepare GCCM samples for testing of index properties by hydration of the GCCM through full immersion.

In the uncured state, GCCMs like other extensible reinforcing geosynthetics, can be evaluated using tensile strength as one of the standard index tests. GCCM physical properties change with the addition of water and in service the GCCM becomes a thin rigid element. Once cured, GCCMs performance is better evaluated by a flexural bending test, which considers flexural strength. The performance requirements of a GCCM should meet, as a minimum, those stipulated in ASTM D8364 Type II classification for GCCM's.

The ASTM International Standards Organisation and its D35 Geosynthetics Committee has published a number of standards specifically for GCCMs to address the shortfalls in using traditional geosynthetic or concrete or fibre reinforced cement sheeting standards. These GCCM specific standards enable consistent, accurate reporting of essential GCCM properties. They include:

- ASTM D8364 'Standard Specification for GCCM materials'
- ASTM D8030 'Standard Practice for Sample Preparation for GCCM's'
- ASTM D8058 'Standard Test Method for Determining the Flexural Strength of a GCCM Using the Three-Point Bending Test'
- ASTM D8329 'Standard Test Method for Determination of Water/Cementitious Materials Ratio for GCCM's & Measurement of the Compressive Strength of the Cementitious Material Contained Within'

These standards have been created to set the benchmark levels for manufacture and testing of GCCM properties, conducted on GCCM specimens that have been prepared in a manner that is consistent with their use in the field and are therefore representative of material installed in real-world operating conditions. The physical performance properties of GCCMs can be assessed to the GCCM specific ASTM standards to ensure they are suitable for erosion control and containment applications:

As shown in Figure 2, CCX-M™ consists of 4 layers: - A high density cementitious mix contained between two geotextile layers stitched together with high-tensile linking fibres. A waterproof polymeric layer is fusion bonded on the bottom geotextile layer to create a very low permeability composite.

2. APPLICATIONS IN CANAL LINING

The US Bureau of Reclamation (USBR) ten-year field tests as reported by Swihart & Haynes (2002) demonstrate that a geomembrane with a concrete cover provides the highest B/C (Benefit to Cost) ratio when compared to exposed geomembranes, fluid applied membranes and concrete alone.

Whilst GCCMs provide similar long-term benefits to a geomembrane with concrete cover, they also offer a number of additional benefits:

- **Installation Damage.** The risk of damage to geomembranes during installation is well documented (Schiers 2009). Some studies have attributed as much as 71% of geomembranes leakage to damage during the installation of a protective top cover. Whilst there is no substitute for careful installation, the prefabricated nature of the protective layer in GCCMs significantly reduces risk of puncture during installation.
- **Side Slope Incline.** The internal fibre matrix of GCCMs prevents the dislocation of the dry concrete powder during transportation and the wet mix during hydration. This allows GCCMs to be laid on vertical slopes without slump or strength loss. By contrast non-reinforced concrete is typically unstable during placement on side slopes steeper than 1.5H:1V as reported in Giroud & Plusquellec (2017).

- **Constant Thickness.** The prefabricated nature of GCCMs allows for tightly defined thickness control which helps to avoid the long-term cracking often associated with thickness variation present in poured concrete as reported in Giroud & Plusquellec (2017).

- **Manning's Value.** The Manning's value provides an indication of resistance to hydraulic flow and allows engineers to calculate a suitable channel profile and slope for a given flow rate requirement. A 'low' Manning's value represents materials with less resistance to flow compared to those with a 'high' Manning's value. GCCMs have been tested by the Texas Research Institute (TRI) in the USA (2016) and shown to have a Manning's value of 0.011. This is similar to a smooth poured concrete surface (0.01) and significantly lower than a rough poured concrete surface (0.015).

- **Composite Liner Effect.** The prefabricated nature of GCCMs means that the geomembrane liner on the lower surface is in intimate contact with the concrete impregnated fibre matrix on the upper surface - an inherent aspect of the manufacturing process. This results in a reduced leakage rate when compared to a geomembrane liner on its own, due to the "composite liner effect" as discussed in Giroud (2016).

- **Embodied Carbon.** A report to assess the carbon footprint of a leading GCCM product using ISO 14040 full Life Cycle Assessment method (Mironov V. 2017), found that when considering raw materials alone, a GCCM (8mm) lined channel contained less than 45% of the embodied carbon of a conventional channel lined with 150mm of poured concrete.

- **Performance in varying climates.** GCCMs should undergo freeze-thaw testing to ASTM C1185 and retain a minimum of 85% of its initial flexural strength. The test method involves cyclic testing of cured sample bars which are then subjected to 200 cycles of freezing at -20°C and thawing at +20°C. GCCMs with similar retained initial flexural strength have been successfully installed in extreme climates such as the artic circle, Canada and Russia with over 15 years of successful field performance. Resilience to erosion, abrasion, impact and vibration:

- **Resilience to erosion, impact and vibration.** GCCMs should be manufactured by filling the internal volume to a defined density. By doing this, the void ratio within the cementitious powder fill is minimised. This ensures very tight control of the water to cement ratio during hydration (by limiting the volume of water able to enter the material and activate the cementitious component). GCCMs control the water cement ratio to approximately 0.3 enabling very high strengths to be achieved. With these high strengths comes high mechanical performance expected of Type II GCCMs.

- **Abrasion Resistance.** GCCMs should be tested to ASTM C1353 for Abrasion Resistance. Depth of wear does not exceed 0.3mm after 1,000 revolutions of a Taber Abrader demonstrating exceptional erosion and abrasion resistance. This is around 3.5 times that shown for a typical 20Mpa concrete that might be used in canal lining applications.

- **Impact Resistance.** GCCMs should be tested to ASTM D5494 Type B for Pyramid Puncture Resistance and demonstrate a minimum capacity of 3.5kN, meeting the requirements for a Type II GCCM. In addition, cattle loading trials have been conducted on GCCMs laid over compacted gravel, to simulate impact loading in the field.

- **Expected Lifespan in Years.** GCCMs should have a minimum design life of 50 years. Life span assessment is based on the European Assessment Document for GCCMs (EAD 080009-00-0301) which includes the following tests:
    - UV & Weathering to BS EN 12224
    - Microbiological Resistance to BS EN 12225
    - Leaching Resistance to BS EN 14415

  - Thermal Ageing to BS EN 14575
  - Abrasion Resistance to ASTM C1353
  - Freeze/Thaw Resistance to BS EN 12467
- **Maintenance.** Whilst the top geotextile layer of a GCCM is critical to the material's performance during manufacture, transportation and installation, it is not crucial to the products long term function.

During manufacturing and transportation, it acts to contain the high-density dry powder fill, maintain the internal volume and prevent dislocation of the fines. During installation it acts as a filter layer allowing water to enter the material whilst preventing the cementitious mix to escape. It also aids uniform hydration and minimises evaporation during the curing stage.

In very abrasive conditions, the top geotextile layer may degrade over time, exposing the encapsulated concrete layer. Typically, abrasion of the top fibres would only occur at significant flow rates and where there is transportation of silt, sand or rock within that flow. This is not typical of most irrigation canals which commonly operate at low flow rates. However, if the top geotextile layer is removed, the specially formulated, high strength OPC based concrete layer is exposed. When tested to ASTM C1353 the depth of wear of this cementitious layer does not exceed 0.3mm - 1000 cycles, around 3.5 times higher than a typical 20 Mpa concrete mix.

3. APPLICTAIONS IN CANAL REMEDIATION

In addition to their use in lining new structures with a consolidated soil substrate, GCCMs are increasingly being used as a method for the remediation of dilapidated concrete infrastructure which may have cracked and spalled. There are a number of specific benefits that GCCMs provide when relining existing water channels:

- **Speed of Install**. Re-lining of in-service water channels is often extremely time sensitive in order that disruption to associated downstream industries, such as hydro-electric plants or agricultural farmland, is minimised. GCCMs are typically ten times faster to install than a poured concrete surface for channel lining applications (Engineers Incorporated 2011).
- **Crack Bridging**. The internal fibre matrix acts to provide tensile reinforcement to the cement/concrete mix and prevent cracks from propagating. This helps to prevent the phenomenon of large crack spread often seen in conventional concrete structures but also provides reinforcement to the geomembrane on the rear surface to increase the co-energy of the composite material. This is particularly important when relining existing concrete infrastructure where the GCCM will need to bridge cracks in the existing substrate. The use of co-energy to compare geomembranes ability to accommodate differential settlement is described by Giroud and Soderman (1995) and further by Giroud (2005).
- **Channel Flow Capacity**. Resurfacing damaged concrete infrastructure with conventional concrete will normally result in a reduction of channel profile and hence flow capacity since concrete pour thicknesses are typically 100-150mm. This can be a significant issue as most channels will have been designed to carry a maximum volume of water, for example to service a specific area of farmland, feed a hydro-electric plant or dissipate storm water from a 1 in 100 storm events. Typical GCCM thicknesses are 5-13mm thick and therefore allow concrete channels to be relined with negligible effect on their flow capacity.

4. GCCM LINING OF A DRAINAGE CANAL EXAMPLE

In June 2022, a GCCM was installed to canalise pumped underground water from settling ponds to a river outlet in Kolwezi, Democratic Republic of Congo. Due to the high water table and prevalence of subsurface water, continuous pumping is required to lower the water table. This underground water is pumped into ponds which allow sediments to settle prior to canalising to the local river outlet - with the settling ponds to the river outlet being approximately 4km long.

The canal needed to have a low level of permeability to ensure water transported along the 4km length does not permeate back into the soil. In addition to the pumped water, the canal needed to have the capacity to drain stormwater collected from the catchment above ground. As the subgrade running the length of the canal are lateritic the flow rates in which the canal would be operating under would have caused the soil to erode.

A number of lining solutions were considered including a geomembrane underlay with poured concrete, shotcrete or riprap protection. However, due to the scale of the canal and proximity to the rainy season, a fast and effective solution was needed. Due to the canal being used to divert pumped water as well as storm water, the lining solution needed to withstand and sustain flow rates of up to 6m/s as well as abrasion caused by sediment accumulated by storm water runoff.

Figure 3. Aerial views of 4km long drainage canal

A GCCM was chosen as the preferred lining solution due to it being rapid to install - with very little need for a large workforce and plant. This GCCM should withstand significant flow rates, protect the canal from any erosion and mitigate any water from permeating the soil.

Prior to the GCCM being installed, the canal had to be excavated and profiled to specification. The canal profile with an invert width of 2m, top width of approximately 7m, depth of 1.5m and side slopes of 1:1.5 was excavated to the requisite falls and compacted to between 90 and 95% MOD AASHTO. All vegetation and protruding objects were removed, and voids filled to achieve a uniform profile. Anchor trenches at least 150mm deep were excavated parallel to the canal profile, offset at 300mm from the profile crest.

Figure 4. 8m wide canal profile preparation

Figure 5. GCCM deployment from excavator deployed spreader beam

Once the canal was excavated, 1400kg GCCM bulk rolls, 50m long by 1.9m wide, were brought onto site and lifted into place using an excavator with a spreader beam attachment. Using the excavator boom arm, the GCCM was laid transversely across the width of the canal. The material was cut to length using basic hand tools to ensure a minimum run-out of 100mm within the anchor trenches. Each layer of GCCM was overlapped by 100mm in the directional flow of water. Prior to jointing, the overlapping layers intermediate flat round head pegs were installed through the underlap of each joint at the transition from side slope to invert. This served a dual function of counteracting hydration shrinkage whilst the GCCM cured as well as resisting hydraulic shear under the anticipated flow conditions.

Figure 6. Cutting GCCM to length

Figure 7. Inserting anchor pegs

Figure 8. Inserting intermediate pegs

The GCCM geomembrane backing is cleaned and overlapping layers thermally bonded with a handheld hot air welder to achieve a low permeability joint. Stainless steel screws at 100mm spacings, 50mm from the overlap edge were used to further secure the overlapping layers. The GCCM was pegged within anchor trenches and the backfilled with non-erodible fill. Transverse anchor trenches were installed at the upstream and downstream ends of the canal as well as transitions at all structures crossing the canal. These transverse anchor trenches were excavated to a minimum width and depth of 300mm. The GCCM was terminated within these trenches and then filled with poured concrete.

Figure 9. Cleaning GCCM backing

Figure 10. Thermally bonding overlaps

Figure 11. Screw fixing overlaps

The weather conditions during the day were hot, dry and windy. To ensure the GCCM did not cure prematurely the material was hydrated a minimum of 3 times to ensure adequate hydration. These hydrations were carried out at 30-minute intervals with no trafficking of the GCCM surface permitted. All material was hydrated on the day it was installed.

Figure 12. Transverse anchor trenches

Figure 13. GCCM Hydration

Figure 14. Drainage Canal in operation

Due to the speed and ease of application, GCCM was installed at an average rate of 10 rolls (950m2) per day with a team of 10 installers. The installation team was spilt into teams each designated by task which involved laying, jointing, fixing and hydrating.

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NATURAL CAPACITY OF UN-DREDGED EARTH DRAINAGE DITCHES IN TREATMENT OF DRAINAGE WATER (CASE STUDY: GUILAN, IRAN)

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ABSTRACT

Protection of water resources is extremely important, especially in water-scarce regions like Iran. Presence of Nitrogen and phosphorus in drainage water from agricultural lands is common, and as non-point pollutants, they can lead to eutrophication and deterioration of downstream water resources. This study aimed to investigate the capability of natural un-dredged drains to remove nitrogen and phosphorus in drainage water from paddy fields in Guilan province, Iran. For this purpose, the effect of dredged (G_1) and un-dredged (G_2) earth ditches (with the presence of Reed, Typha, and Sparganium plant species) was studied on drainage water treatment for two levels of high (C_1) and low (C_2) concentration of pollutants (Urea and Triple Superphosphate). The initial content of nitrogen and phosphorus in water, sediment, and plants was measured to compute the mass balance components in G_1C_1, G_1C_2, G_2C_1 and G_2C_2 treatments. According to the results of variance analysis, the amount of nitrogen and phosphorus removed was significant at 5% level. The highest percentage of nitrogen and phosphorus removal was observed in G_2C_2 treatment at the rate of 9.71 and 11.45 percent per 100 meters of drain length, respectively. From which, the highest percentage of nitrogen and phosphorus removal was through phytoextraction processes in G_2C_2 treatment at the rate of 37.06% and 61.69% and seepage losses in G_2C_1 treatment at 27.42% and 20.04% per 100 meters, respectively. Also, the highest sediment absorption was observed for nitrogen in the G_2C_2 treatment, and for phosphorus in the G_1C_1 treatment at a rate of 39.88% and 34.95% per 100 meters, respectively. Therefore, our analysis showed that natural un-dredged drainage ditches have a good potential for removing common pollutants leaving agricultural lands and can significantly ameliorate the quality of the drainage water entering downstream water sources.

Keywords: Drainage water treatment, Dredged and Un-dredged drains, Agricultural wastewater, Nitrogen, Phosphorus, Eutrophication.

INTRODUCTION

Population growth has led to enhancement of agricultural activities to comply with human food demands. Non-point pollution are imperative from agricultural fields [e.g., nitrogen and phosphorus] (Kling et al., 2014; Scavia et al., 2014). Un-controlled use of pesticides and fertilizers, as well as lack of management in fields, result in remarkable sources of pollutants in drainage water (Navabian et al., 2016). Rice is a vital staple food for half the world's population, and particularly in Iran. However, the cultivation of rice in paddy fields requires a substantial volume of irrigation water and fertilizers, leading to the generation of large volume of unconventional water that can have detrimental environmental effects (Lampayan et al., 2015**)**. In this study, the potential of natural drainage ditches found in paddy fields of northern Iran for the treatment of drainage water in examined. The approach can be employed as an innovative and cost-effective BMP_s for treating drainage water and mitigating its role in pollution

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of downstream water resources. Drainage ditch treatment is similar to the processes in constructed wetlands. Drainage ditch treatment, however, has different hydraulic conditions and are more complicated (Collins et al., 2016). The treatment of contaminated agricultural wastewater can involve a variety of processes, including plant absorption, sediment surface absorption, and microbial decomposition in vegetated drainage ditches (Baker et al., 2016; Zhao et al., 2020, Zhang et al., 2016a; Vymazal and Brezinova, 2018; Wang et al., 2019**).** Absorbing the nutrients from the drainage water, increasing the hydraulic retention time, reducing flow rate, and exerting roughness, are among fundamental changes in water ditches due to the growth of vegetation (Kumwimba et al., 2017). New perspectives on the pollution treatment capabilities of vegetated drainage ditches, including the effects of diverse crops and processes, have been presented in recent studies (Zhang et al., 2016, 2020; Wang et al., 2019; Liu et al., 2018; Luo et al., 2018; Kumwimba et al., 2018**).** The primary goals of this study were: (1) to assess the impact of vegetated drain ditches on the treatment of varying concentrations of nitrogen and phosphorus; and (2) to investigate the integrated effects of the aforementioned factors on the potential of nitrogen and phosphorus removal.

MATERIAL AND METHODS

2.1 The experimental site, drainage ditches, nutrients concentration

An experiment was conducted in paddy fields of the Iranian National Rice Research Institute (INRRI), situated at a latitude of 37°12'N, a longitude of 49°38'E. The annual average precipitation is approximately 1350 mm, and the annual average temperature is 15.9 °C. The experiment was conducted in two distinct ditches, namely dredged (G_1) and un-dredged (G_2) ditches, nestled in the northern and eastern regions of the paddy fields, respectively (Figure 1). The selection of ditches was carefully considered to guarantee the efficacy of treating drainage water under both dredged and un-dredged conditions. There were no side water entrances or exits along the two selected sections. Table 1 displays the characteristics of both ditches. Two different concentrations of pollutants were employed, high (C_1) and low (C_2) concentrations, to assess the potential of ditches in removing pollutants. The applied concentration varied based on the dimensions of each ditch. Namely, high and low concentrations of fertilizers were developed by injecting two sets of 45 and 22.5 kg for G_1 and 12 and 6 kg for G_2, respectively. The pollutants were poured into the ditches simultaneously and with the equal mass. Four treatments were investigated on the impact of both types of ditches and nutrient concentrations, namely G_1C_1, G_1C_2, G_2C_1, and G_2C_2.

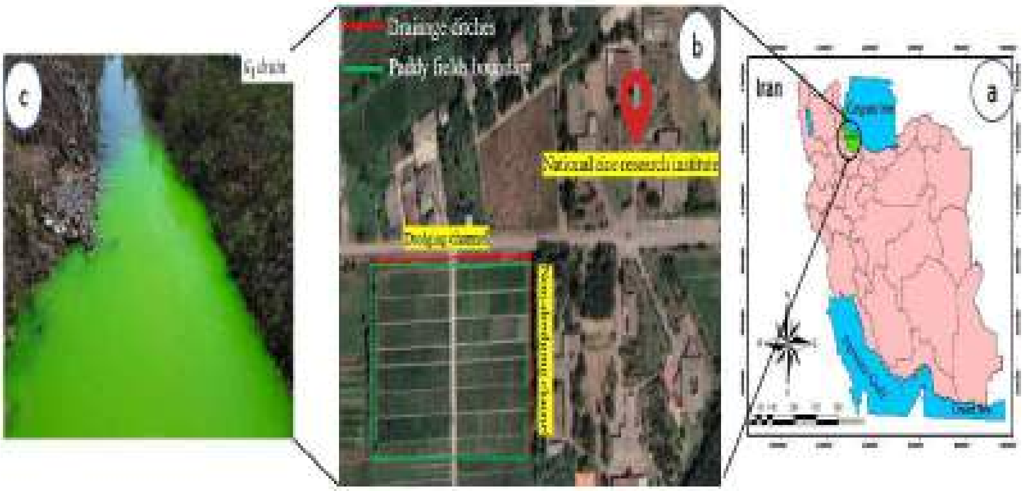

Figure 1. Location of case study: a) Iran’s country map and the location of Guilan province; b) paddy fields and the two investigated drainage ditches; c) dredged ditch after injection of the tracing dye.

Table 1. The characteristics of drainage ditches

Drain type	Shape	Length (m)	Depth (m)	Width (m)	Wetted Perimeter (m)	Longitudinal Slope (m/m)
$\boldsymbol{G_1}$	Rectangle	200	3.36	3.20	6.8	0.0115
$\boldsymbol{G_2}$	Rectangle	100	2.14	2.93	3.6	0.0092

2.2 Water, sediment, and plant sampling

Before starting the experiment, water, soil, and plant samples were collected to determine the existing condition. Introduction of nutrients were set at 50 (for N) and 20 (for P) $mg\,lit^{-1}$ concentrations, taking into account the length, width, and average depth of the ditches. Fluorescein sodium was injected as a tracer element to determine the residence time of water flow along the drains (Figure 1). Once the fluorescein sodium reached the end of the drain span, sampling of the drainage water samples were collected at the end of the drains for both concentrations, each with three replications. Sampling was conducted at 15-minute intervals until the traced water flow completely disappeared. Drainage water was sampled using a sampling device, with a volume of 1 liter and based on the integration method along the full depth of flow. Air and water temperature were monitored during the experiment (figure 2). Drainage water samples were analyzed and the density and type of plants in drain G_2 were determined at the beginning, middle, and end of the drain simultaneously. The existing vegetation density in drain G_2 was determined using $1m \times 1m$ square wooden frame measuring device (Table 2).

Table 2. The density and types of the vegetations in the un-dredged ditch

Ditches length	**First**	**20 m**	**40 m**	**60 m**	**80 m**	**100 m**	**105 m**
Number of plants	36	31	33	17	14	18	19
Type of plants	Sparganium	Reed	Reed	Reed	Typha	Typha	Typha
Type of plants	Reed	Sparganium	Typha	Typha	Typha	Typha	Typha

Sediment sampling were also collected at the beginning, middle, and end of both channels, using an auger sampler. To measure the inlet and outlet flow discharge, WSC flumes were installed at the beginning and end of both ditches. The selection of $WSC\ T_5$ and $WSC\ T_4$ flumes for drains G_1 and G_2, respectively, was based on the average discharge flow (Eslami et al., 2016) (Table 3).

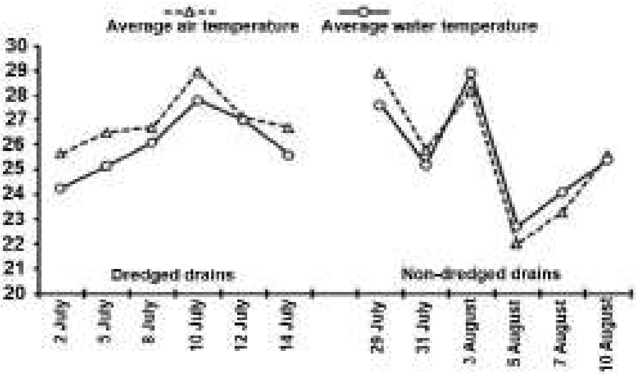

Figure 2. Average air and water temperature changes in different months

Table 3. The values of the inlet and outlet volume and discharge

Experiment number	**Dredged ditch**			
	Inlet discharge (lit/s)	**Inlet volume (m3/d)**	**Outlet discharge (lit/s)**	**Outlet volume (m3/d)**
1	18.24	1576.13	18.10	1563.68
2	19.74	1705.48	19.60	1693.17
3	16.19	1398.76	16.05	1386.76
4	17.27	1492.36	17.13	1480.17
5	15.71	1356.97	15.57	1345.06
6	15.85	1369.44	15.71	1357.45
	Un-dredged ditch			
1	4.16	359.00	4.08	352.64
2	3.52	303.86	3.45	298.03
3	3.65	315.70	3.58	309.75
4	3.12	269.76	3.06	264.29
5	3.55	306.80	3.47	300.35
6	3.45	298.03	3.38	292.26

2.3 Water and pollutant mass balance

Water Infiltration along the drain span was calculated from the water balance using Eq. (1).

$$V_{inf} = V_o + V_{ev} - V_i \qquad (1)$$

Where V_{inf} is the infiltration ($m^3 day^{-1}$); V_0 and V_i are the outlet and inlet drainage water ($m^3 day^{-1}$); V_{ev} is the evaporation ($m^3 day^{-1}$).

Daily evaporation data from a nearby agricultural meteorological station were used to estimate local daily evaporation rates. The rate of nitrogen and phosphorus removed along the drain is influenced by different processes such as infiltration losses, sediment surface absorption, plant uptake, and volatilization. The nitrogen and phosphorus mass balance in the un-dredged ditch is determined from Eq. (2) (Zhang et al., 2016b).

$$Q_r = Q_o + Q_{sa} + Q_v + Q_p + Q_{dn} + Q_{inf} - Q_i \qquad (2)$$

Where Q_r is the mass of removed nitrogen and phosphorus; Q_i and Q_o are the inlet and outlet mass of total nitrogen and phosphorus; Q_{sa} is the mass of surface sediment adsorption; Q_v is the mass of volatilization losses; Q_{dn} is the mass of denitrification losses; Q_p is the mass of plant uptake.

To plot time-concentration were graphed using measured Concentrations. Total pollutant output was estimated via fractionation method. Mass of nitrogen and phosphorus losses via infiltration were calculated using Eq. (3).

$$Q_{inf} = V_{inf} \times C \qquad (3)$$

Where V_{inf} is the infiltration volume ($m^3 day^{-1}$); C is total nitrogen and phosphorus concentrations from collected drainage water samples (ppm).

Sediment was sampled at the beginning, middle, and end of the ditches before and after each experiment to determine the changes resulting from nutrient injections. Mass of nitrogen and phosphorus losses via sediment surface absorption were calculated using Eq. (4).

$$Q_{sa} = SW \times C \qquad (4)$$

Where SW is the weight of existing sediments along the ditch (using specific gravity, length and cross section of the ditches); C is total absorbed nitrogen and phosphorus concentrations in sediment samples ($mg\ kg^{-1}$).

Based on the amounts of nitrogen and phosphorus absorbed by surface sediment and infiltration the share of other removal factors were determined. Ultimately,the effect of drain type and concentration on removed nutrient, surface absorption, seepage losses were statistically determined using Duncan's 5% test.

RESULTS AND DISCUSSION

3.1 Effect of drain type and concentration level on nitrogen and phosphorus load

The amount of nitrogen and phosphorus load in drainage water is significantly affected by the drain type and level of injected concentration at a significant level of 1%. The results of Duncan's 5% test demonstrated that the highest amount of nitrogen and phosphorus load was estimated at 14.98 and 6.28 kg, respectively, for the G_1 drain. The results show that from G_1 drain to G_2 drain, despite its longer length and larger dimensions, the amount of pollutant load is decreased by 75% and 74%, respectively, for the two concentrations. This increased treatment capacity in the un-dredged ditch can be attributed to the increase in the retention time and the effect of growing vegetation. Moreover, the results showed a direct correlation between the outlet nitrogen and phosphorus loads and the application concentration. By reducing the concentration level from C_1 to C_2, the amount of pollutant discharged decreased by 52% and 51%, respectively (Figure 3-a). By considering the interaction of the factors, it was determined that the highest and lowest nitrogen and phosphorus load occurred in treatments G_1C_1 (20.15 and 8.46 kg) and G_2C_2 (2.48 and 1.04 kg), respectively (Table 4). The results showed that the absence of vegetation in the dredged ditch and higher concentration of nutrients would increase the load of pollutant outlet. Similar results were observed in Sisley et al. (2020), Zhang et al. (2020), Vymazal and Brezinova (2018), and Collins et al. (2016).

3.2 Drain type and concentration level effect on removed nitrogen and phosphorus

To accurately compare the amount of removed pollutants from different drain types, the results are expressed in dimensionless figures based on every hundred meters of ditch not the whole length of span. The variance analysis showed that drain type significantly affected the removal of nitrogen and phosphorus at a significant level of 1%, but the different levels of injected concentration only affected phosphorus at level of 1%. Also, the interaction effect factors were not significant for both pollutants. The effect of drain type and concentration level on the removed nitrogen and phosphorus is presented in Figure 3-b. The results indicated that, despite the longer length of drain G_1, the vegetation in un-dredged ditch led to 75% and 68% more nitrogen and phosphorus removal which showed the significant effect of vegetation in removing pollutants (Sisley et al. (2020), Zhang et al. (2020). Additionally, the concentration level had a direct relationship with pollutant removal. The highest percentage of nitrogen and phosphorus removal, estimated at 9.71% and 11.46%, respectively, was related to treatment G_2C_2 (Table 4). However, Table 4 illustrate that considering the larger length and cross-sectional area of the dredged drain, the amount of nitrogen and phosphorus removal was 40% and 55% higher than the un-dredged drain.

3.3 Seepage losses in different drain type and for different concentration levels

Both drain type and concentration level significantly affected the seepage losses of nitrogen and phosphorus at a significant level of 1%, but the interaction of two factors did not have a significant effect. The results showed that the percentage of nitrogen and phosphorus seepage losses was higher in G_2 drain, and also maximum losses were related to C_1 concentration level. By reducing the concentration level from C_1 to C_2, the amount of phosphorus seepage losses decreased by 40%. The interaction effect of two factors showed that the highest percentage of nitrogen (27.42%) and phosphorus (20.4%) seepage losses is in treatment G_2C_1, which was 6.36% and 8.90% of the total removed nitrogen and phosphorus, respectively (Table 4). Overall, these findings suggest that the un-dredged vegetated drainage ditches with a lower concentration levels of nutrients can effectively reduce nitrogen and phosphorus seepage losses along the drains.

3.4 Surface sediment absorption for different drain types and at different concentration levels

The amount of surface sediment absorption of nitrogen and phosphorus was found to be significantly affected by drain type at 5% level. However, the concentration level factor and its interaction were not found to be significant. The highest surface absorption of nitrogen is related to G_2 drain, however, there is no significant difference with G_1, which has a larger cross-sectional area and wetted perimeter. It is completely opposite for the phosphorous, for which the highest surface absorption was observed in drain G_1. The effect of concentration level on nitrogen and phosphorus absorption showed that the highest absorption occurred in drain G_2 and G_1, respectively (Figure 3). Sediment surface absorption is a function of sediment load, thickness and wetted perimeter, texture of sediment, sediment specific surface area, drain length, and flow cross section. In drain G_2, due to the high-density of vegetation growth, smaller length and cross-sectional area, the role of surface absorption of sediment in phosphorus removal was less significant. Therefore, due to the fact that phosphorus has a lower seepage potential as compared to nitrogen (immobilization), it should be considered that this pollutant has a higher removal potential in the form of phytoremediation process, and the possibility of transportation of phosphorus as sediment to downstream is reduced. The highest percentage of sediment surface absorption of nitrogen was at 39.88% in treatment G_2C_2, which constitutes 9.71% of the total nitrogen removed. The highest and lowest surface absorption of phosphorus was related to G_1C_1 and G_2C_2 treatments, respectively, which, are significantly different from each other (Table 4). The results show that in the presence of vegetation, phosphorus surface absorption has the least contribution to phosphorus removal. the highest and lowest amount of nitrogen surface absorption was related to G_1C_1 (337.56 gr) and G_2C_2 (119.16 gr) treatments. The highest level of nitrogen absorption in the G_1 drain is 331.74 gr, which is significantly different from the G_2 drain (61% lower). It can be concluded that in the absence of vegetations, the wetted parameter plays the main role on surface absorption of nutrients. Also, nitrogen surface absorption is more dependent on the physical characteristics of ditches as compared to the concentration level. Phosphorus surface absorption related to drain G_1 was observed at the rate of 260.41 gr, which was significantly different from drain G_2 (94% lower). As a result, the surface absorption of phosphorus in the sediment accounts for the lowest contribution of phosphorus removal in the G_2 drain. In addition to the physical characteristics of the drains, phosphorus surface absorption is also dependent on the concentration level.

3.5 phytoremediation, denitrification, and volatilization for different Drain types and for different concentration levels

Table 4 shows the discussed nitrogen and phosphorus mass balance. It can be seen that in each experimental treatment, for the ditch physical characteristics (length and cross-sectional area) and vegetation conditions, the contribution of each process in removing nitrogen and phosphorus is different. Recognizing the amount of nitrogen and phosphorus removed, seepage and sedimentation losses, the remaining nutrient reduction can be attributed to combined effect of phytoremediation, denitrification and volatilization, which can not readily be separated. Roots, stems and submerged organs of the growing plants play the main role in plant absorption, which depends on the density and type of vegetation. The role of phytoremediation, volatilization, and denitrification in the removal of nitrogen and phosphorus is presented in the last column of Table 4. In drain G_2, according to the plant species in this case study (Reed, Typha, Sparganium) and the density of these plants, it is almost possible to completely remove pollutants. Another mechanism of nitrogen removal is the denitrification process, which depends on the submergence intensity, retention time, and water temperature. Zhang et al. (2020) also reported the role of plant, surface absorption and denitrification as 12.4-21.5 and 38.9-62.7 percent respectively, which is consistent with our results.

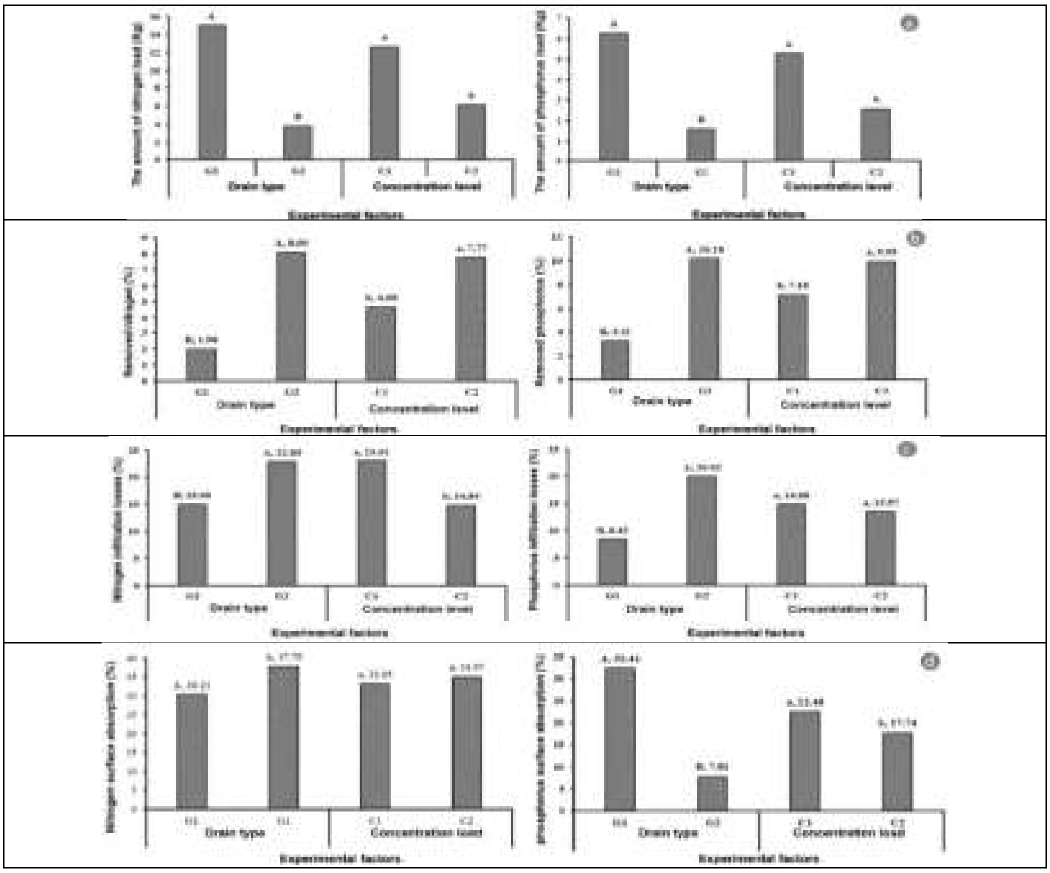

Figure 3. The effect of drain type and concentration level on: a) pollutants load, b) removed pollutants, c) infiltration losses, d) surface sediment absorption

Table 3. Mass balance of Nitrogen and phosphorous loads

Treatment	Average concentration (ppm)	net input (gr)	Removed pollutant		Infiltration loss		Sediment absoption		Phytoremediation and …	
			(%)	(gr)	(%)	(gr)	(%)	(gr)	(%)	(gr)
Nitrogen										
G_1C_1	50	20700	1.3	554	18.6	206	30.4	337	1.1	10
G_1C_2	25	10350	2.6	542	11.4	123	30.1	325	5.5	92
G_2C_1	20	5520	6.3	368	27.4	106	35.7	138	32.1	124
G_2C_2	25	2760	9.7	284	18.3	54	39.8	119	37.1	110
Phosphorus										
G_1C_1	20	8901	2.5	445	9.7	86	34.9	331	5.3	47
G_1C_2	10	4450	3.9	350	7.1	50	29.8	209	13.0	91
G_2C_1	20	2373	8.9	221	20.0	46	10	23	65.2	151
G_2C_2	10	1186	11.4	142	20.0	30	5.6	8	69.6	104

CONCLUSIONS

In this research, the treatment capacity of un-dredged ditch was investigated and compared with a dredged ditch. The effect of two levels of injected nutrient concentrations and drain type was field examined. To evaluate the role and difference of the two ditches in natural treatment and removal of nitrogen and phosphorus, a mass balance was developed, for which the components include seepage losses, sediment surface absorption, and combined effect of plant uptake, denitrification, and volatilization. The results of removed nitrogen and phosphorus showed that the un-dredged drain has a much higher potential for pollutant removal, despite the smaller length and cross-sectional area compared to the dredged drain. The reasons for this observation can be collectively attributed to the decrease in the speed of water flow and pollutant adsorption due to the higher roughness coefficient, plant phytoremediation, and the increased biological processes (denitrification). The share of pollutant removal due to seepage from the channel bed in G_1 drain was calculated as 15% and 8.42% for nitrogen and phosphorus, and 22.85% and 20.02% for G_2 drain. The combined effect of phytoremediation, denitrification and volatilization was estimated at 1.09% and 5.32%, for the G_1 and G_2 drains is respectively, which was 32.11% and 19.65% of the total pollutant removed. This result shows the significant role of phytoremediation in the treatment of drainage water of paddy fields, which can be used in improving the quality of drainage water. On the other hand, not dredging of the drains leads to a decrease in the drainage capacity, especially in flood conditions. But the discharge without treatment of the drainage water to the environment will result in pollution of surface water sources, which have its own negative and detrimental consequences. Overall, the most sustainable practice starts with source control practices, namely improved field water management to lower drainage water production in addition to a more precise use of chemicals.

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THE PROBLEM OF ADAPTATION OF DRAINAGE SYSTEMS TO CLIMATE CHANGE IN BELARUS

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ABSTRACT

The research has been carried out and the statistical significance of changes in the regime of climatic characteristics over the past thirty years has been established on the example of the southwestern part of Belarus. A significant impact of drainage amelioration has been established. It corrects the global trends in climate change in the region under study, which is expressed in a change in the moisture supply of the territory.

There is a shift in the boundaries of agro-climatic regions according to the conditions of heat supply (the sum of accumulated air temperatures > 10 °C) by about 40-50 km in the northeast-southwest direction. The territory of Belarus began to receive additional thermal resources, which predetermine the possibility of introducing new, more moisture-loving and highly productive types of crops into circulation.

The climatic conditions of Belarus are losing the features of continentality due to the smoothing of the annual amplitudes of air temperatures and precipitation. The conditions of natural moistening, along with thermal resources, in combination become more favorable and, as a result, reduce the shortage of water consumption for crops. Saving irrigation water during the growing season is about 150-200 m^3/ha, which is a significant value and can affect the reduction of agricultural costs.

An analysis of the trends of the studied characteristics shows that the noted dynamics of natural heat and moisture supply will continue in the future. In this regard, the methods of designing amelioration and water management facilities should be adjusted.

Keywords: Water amelioration, Climate change, Drainage Systems, Belarus

1. INTRODUCTION

The most weather-dependent sector of the economy of Belarus and Russia is agriculture. Adverse weather events provoke up to 42% of damage. Belarus is characterized by regional problems caused by climate change, as well as for the rest of the continental part of Europe, and by the typical problems only for the country, associated with historically prevailing agricultural conditions and the economy as a whole.

Specific consequences are the possible consequences of the impact of climate change on drained lands and amelioration systems, which were built during the period of large-scale drainage amelioration in 1960-1980. The total area of ameliorated land in the republic is 16% of the country area, 85% of which is agricultural land. The area of ameliorated land with using closed (one-way) drainage is 65%. And only 22% of the ameliorated land area has a drainage system built up with bilateral (two-way) regulation of the water regime, where it is possible to regulate the water regime in dry periods.

In conditions of long-term operation, amelioration systems and their elements fail. The consequence of this is a violation of the optimal agrotechnical terms for sowing and harvesting agricultural plants, the conditions for their cultivation and a significant decrease in the productivity of ameliorated land.

Given the expected climate change towards its aridification and an increase in the number of extreme events, water amelioration will play an extremely high role in the adaptation of

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agriculture and, above all, crop production. It is very likely that the irrigation network and its infrastructure reconstructed and modernized need to be expanded. Likewise, modernization of excess water diversion systems will be required to prevent and reduce damage from frequent high flows and floods.

It is important to predict trends in the development of negative processes and degradation of irrigated lands, their impact on adjacent territories, determining the nature of seasonal, annual and long-term dynamics of the level, mineralization and chemical composition of groundwater, taking into account climate change. The dynamics of moisture reserves in the root layer of the soil should be constantly monitored during the growing season; an assessment of the amelioration situation in the dynamics of its development, and a forecast of possible changes in subsequent years should be carried out too.

The presence of long-term forecasts and taking into account the direction of climate change allows timely implementation of the necessary measures for water accumulation or, on the contrary, diversion of excess water using amelioration systems, however, changes in the corresponding design parameters should be reflected in the engineering and construction normative documentation.

In the last decade, the issue of the influence of natural and anthropogenic factors on the change in the regime of climatic characteristics has been widely discussed in the scientific literature. Global climate warming is linked, first of all, with anthropogenic emissions of "greenhouse" gases into the atmosphere. Over the past century in the Northern Hemisphere, there has been an increase in the average annual temperature of the surface air layer by 0.6°C, and by the middle of the 21st century it is expected to increase by another 2.5°C or more (Metreveli G. S. et al. 2001; Loginov V. F. 1996; Loginov V. F. et al. 2003; Orru H. et al. 2017). Such transformations are very significant for the territory of Belarus and can have a serious impact on the economy. In particular, an increase in heat supply will lead to an adequate increase in the duration of the growing season, which will eventually allow, upon reaching the optimal moisture supply, to obtain high and stable crop yields. An increase in air temperatures inevitably entails structural changes in the natural humidification regime, primarily an increase in total evaporation and asymmetric transformations in the precipitation regime. The predicted changes in the heat and moisture supply of the territories will entail the need to take into account when planning the placement of crops, designing water management and land amelioration measures. The most important anthropogenic factor that influenced the regional climate of Belarus was the large-scale drainage amelioration carried out on the territory of Polesie in 1965-1984. (Loginov V. F. 1996; Loginov V. F.et al. 2003; Meshik O. P. 2005).

The main purpose of the work is to assess the current regimes of hydromeliorations in a changing climate on the example of the southwestern, most meliorated part of Belarus.

2. METHODS

The object of the research is the deficits or excesses of water consumption of the main agricultural crops. Currently, various models have been proposed. They describe the dynamics of soil moisture reserves with varying degrees of discreteness and accuracy, but the most acceptable for practical purposes is the water balance method.

$$W_i = W_{i-1} + X_i - Z_{oi} - Y_i + G_i - J_i \ , \qquad (1)$$

where W_i, W_{i-1} – soil moisture reserves, respectively, at the end and beginning of the calculated time interval (t); X_i – amount of precipitation for the calculation period; Z_{oi} – optimal water consumption of an agricultural crop (optimal total evaporation of the natural vegetation cover) for the calculated time interval; Y_i – surface runoff; G_i – soil component of the water balance for the same period; J_i – infiltration of soil moisture from the aeration zone into the deeper layers of soil over time (t).

To assess modern transformations taken into account in the calculations of climatic characteristics, as well as, as a result, the obtained hydro-amelioration norms, we adopted seventy-five-year observation series from 1945 to 2019 in our research. The original series is divided into two parts: from 1945 to 1974 – before the active impact of amelioration construction on the environment (land amelioration peaked in 1972–1974) and from 1975 to

2019 – the period of stable functioning of the constructed irrigation and drainage systems. We described the methodology for calculating hydro- amelioration norms in details by Volchak A et al. (2020).

3. RESULTS AND DISCUSSION

In order to assess the differences in the modes of formation of the natural moisture content of the territory for the established periods, we obtained the differences in the average long-term amounts of atmospheric precipitation for 1975-2019 and 1945-1974 (Table 1).

Table 1. Average long-term sums of atmospheric precipitation and their differences in the studied area, mm

	Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**4-10**	**Year**
Brest	1975-2019	36	31	30	41	56	68	80	71	55	40	39	41	411	588
	1945-1974	30	36	27	35	50	76	76	73	48	44	45	38	402	579
	difference	**6**	**-5**	**3**	**6**	**6**	**-8**	**4**	**-2**	**7**	**-4**	**-6**	**3**	**9**	**9**
Pruzhany	1975-2019	35	29	33	38	59	74	85	64	58	40	40	42	418	596
	1945-1974	29	31	25	35	53	81	70	76	48	43	45	38	406	572
	difference	**6**	**-2**	**8**	**3**	**6**	**-7**	**5**	**-12**	**10**	**-3**	**-5**	**4**	**12**	**24**
Pinsk	1975-2019	35	28	32	39	53	80	81	56	59	44	41	41	412	587
	1945-1974	30	30	29	32	52	65	71	64	40	49	45	39	373	545
	difference	**5**	**-1**	**3**	**7**	**1**	**15**	**10**	**-8**	**18**	**-5**	**-5**	**2**	**39**	**42**
Ivatsevichi	1975-2019	41	33	38	43	57	71	87	54	60	40	44	50	412	618
	1945-1974	32	33	27	38	61	68	78	67	46	49	47	39	407	584
	difference	**9**	**0**	**11**	**5**	**-4**	**4**	**9**	**-13**	**14**	**-9**	**-3**	**11**	**5**	**34**
Gantsevichi	1975-2019	42	33	39	43	53	85	87	64	59	45	47	49	436	645
	1945-1974	36	36	31	38	59	70	74	73	49	54	53	43	417	616
	difference	**5**	**-4**	**9**	**6**	**-6**	**15**	**13**	**-8**	**10**	**-10**	**-6**	**5**	**19**	**30**
Baranovichi	1975-2019	38	30	37	37	54	83	92	62	59	41	40	47	428	620
	1945-1974	29	29	29	39	57	74	73	65	49	48	51	39	405	581
	difference	**9**	**1**	**8**	**-1**	**-3**	**9**	**19**	**-3**	**11**	**-7**	**-12**	**8**	**23**	**39**

As can be seen from the Table 1, the annual precipitation in the studied area increased everywhere from 1.5% in the Brest region to 7.2% in the Pinsk region. For the warm period, the increase is even more significant - 2.2 and 9.5%, respectively. An exception is observed in the Ivatsevichi region, where the increase in precipitation was 1.2% during the warm period. The data in the Table 1 reflect the significance of the anthropogenic factor- large-scale amelioration in the formation of the atmospheric precipitation regime. Since the process of total evaporation is intensive on the ameliorated lands in the first half of the warm period, reaching its peak in July, atmospheric precipitation should increase during this period, that is confirmed by the materials of the Table 1. Basically, there is an increase in precipitation from the beginning of the growing season. period. In July, precipitation increased everywhere, from insignificant amounts in Brest (by 0.5%) to 20.1% in the Baranovichi region. In August, after harvesting, with a decrease in total evaporation, precipitation should decrease, that is confirmed by the data in the Table 1 - not significantly in Brest (by 0.2%) and by 24.1% in the Ivatsevichi region. The results obtained are in good agreement with the materials of the works of Academician V.F.

Loginov (Loginov V. F. 1996; Loginov V. F. et al. 2003), and the regional nature of the change in the amount of precipitation in the southern ameliorated part of Belarus is clearly confirmed. In the Brest region, the melioration factor is not of great importance. At the same time, the area of ameliorated land in the Brest region is 15.8% of the total area that is significantly lower than the regional average of 22.7%. September is again characterized by positive differences in precipitation amounts, the highest statistical significance of which takes place in the Pinsk region - 30.5%. October is characterized by an insignificant decrease in the amount of precipitation, which is associated with some change in the circulation processes in the atmosphere. Since October, a type of baric field has been formed, an increase in atmospheric pressure has been observed, powerful anticyclones have been formed, leading, as a result, to a decrease in the amount of atmospheric precipitation and an increasing frequency of "Indian summer". In November, the amount of precipitation also continues to decrease. As a result, we can conclude that over the past 45-year period, the regime of natural moisture in the southwestern part of Belarus has significantly transformed, especially in its intra-annual course, in general, it has statistical significance and must be taken into account in engineering calculations. At the same time, it should be noted that the number of days per year with precipitation of ≥0.1 mm remains almost unchanged. In the intra-annual course, only for the cold period, there are slight changes in the number of days with precipitation (±1-2 days), which are in good agreement with the data in the Table 1.

As noted above, the thermal regime undergoes significant changes. The Table 2 shows data on air temperatures for the periods under consideration and their difference in the study area
.

Table 2. Average long-term values of air temperatures and their difference in the study area, °C

	Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Year**	$\Sigma_{4\text{-}10}$	$\Sigma_{>10°C}$
Brest	1975-2019	-2,7	-2,1	1,9	8,2	14,1	16,8	18,6	18,1	13,1	8,1	2,5	-1,5	7,9	97,0	2595
	1945-1974	-4,7	-3,6	0,0	7,7	13,5	17,1	18,5	17,6	13,2	7,5	2,6	-1,6	7,3	95,0	2530
	difference	**2,0**	**1,5**	**1,9**	**0,4**	**0,6**	**-0,2**	**0,1**	**0,5**	**-0,1**	**0,7**	**-0,1**	**0,0**	**0,6**	**2,0**	**65,3**
Pruzhany	1975-2019	-3,6	-3,2	0,9	7,4	13,3	16,2	17,5	17,3	12,4	7,3	1,7	-2,3	7,1	91,4	2412
	1945-1974	-5,9	-4,7	-0,6	6,9	12,8	16,6	17,9	16,9	12,6	6,8	1,9	-2,2	6,6	90,5	2382
	difference	**2,3**	**1,5**	**1,5**	**0,4**	**0,5**	**-0,4**	**-0,4**	**0,4**	**-0,2**	**0,5**	**-0,1**	**-0,1**	**0,5**	**0,9**	**30,2**
Pinsk	1975-2019	-3,7	-3,2	1,2	8,0	14,1	16,8	18,4	17,7	12,7	7,4	1,7	-2,5	7,4	95,1	2532
	1945-1974	-6,3	-4,8	-0,8	7,0	13,3	17,0	18,1	17,0	12,5	7,3	1,9	-2,6	6,6	92,1	2436
	difference	**2,6**	**1,6**	**2,0**	**1,0**	**0,8**	**-0,2**	**0,3**	**0,7**	**0,2**	**0,1**	**-0,2**	**0,1**	**0,7**	**2,9**	**96,3**
Ivatsevichi	1975-2019	-3,8	-3,3	1,0	7,5	13,7	16,6	18,1	17,2	12,4	7,3	1,6	-2,4	7,1	92,7	2455
	1945-1974	-6,1	-4,8	-0,8	7,0	13,1	16,8	18,0	17,0	12,5	6,6	1,7	-2,3	6,5	91,0	2398
	difference	**2,3**	**1,5**	**1,8**	**0,5**	**0,6**	**-0,3**	**0,1**	**0,2**	**-0,1**	**0,6**	**-0,1**	**-0,1**	**0,6**	**1,7**	**57,3**
Gantsevichi	1975-2019	-4,2	-3,8	0,6	7,3	13,4	16,3	17,9	17,0	12,0	6,9	1,4	-3,0	6,8	90,8	2394
	1945-1974	-6,6	-5,1	-1,1	6,8	12,8	16,5	17,7	16,5	11,9	6,3	1,5	-2,7	6,2	88,4	2314
	difference	**2,4**	**1,3**	**1,7**	**0,6**	**0,6**	**-0,2**	**0,2**	**0,4**	**0,2**	**0,6**	**-0,1**	**-0,3**	**0,6**	**2,4**	**80,0**
Baranovichi	1975-2019	-4,4	-4,0	0,3	7,1	13,2	16,1	17,4	17,0	12,0	6,8	1,1	-3,0	6,6	89,7	2355
	1945-1974	-6,6	-5,4	-1,5	6,5	12,8	16,5	17,8	16,9	12,4	6,5	1,2	-2,9	6,2	89,4	2346
	difference	**2,2**	**1,4**	**1,8**	**0,6**	**0,4**	**-0,4**	**-0,4**	**0,2**	**-0,3**	**0,4**	**-0,1**	**-0,1**	**0,5**	**0,3**	**9,2**

There is a fact of climate warming throughout Belarus in the first half of the year (January-May), and the warming in January is so significant that this month ceases to be the coldest of the year. The increase in air temperature in March is associated with a large number of dry winters in the period of 1975-2019, and, accordingly, a decrease in heat consumption for snow melting. Most of the heat began to be spent on heating the air. Of course, this trend should be taken into account when developing economic measures. The increase in winter and spring temperatures leads to an increase in the duration of the growing season of agricultural crops, as a result of which the southwestern part of Belarus receives beneficial thermal resources necessary for the intensification of agricultural production. In general, there is also an increase in the sums of air temperatures for the warm period (April-October). The increase in accumulated air temperatures >10 °C is of particular importance in agriculture. The largest increase typical for Pinsk over the last 45 years is 96.3 °C (3.8%). Taking into account that the sums of accumulated temperatures >10 °C increase in the northeast-southwest direction, over the past 45 years, the boundaries of agro-climatic regions have shifted by a distance of about 40-50 km in this direction.

Heat and water balance calculations were performed differentially for different periods under the same type of soil and hydrogeological conditions (groundwater level regime, water-physical properties of soil, soil type). The Table 3 shows the calculated values of total evaporation. As can be seen, the total evaporation has increased over the last 45 years in almost all months of the warm period. The greatest growth was in the first half of summer (June, July), about 7% in the Pinsk region. These data are in good agreement with the amelioration of the study area, are linked to atmospheric precipitation, which is formed and increases at this time due to local evaporation, as well as to air temperatures. During this period, the greatest heat costs for the process of total evaporation occur, and the temperature of the surface air decreases almost everywhere (Table 2). In general, during the warm period, the increase in total evaporation ranged from 1.2% in Brest to 5.5% in Pinsk.

The 4th table shows the obtained by the heat-water balance method water consumption deficits of 75% supply of the main crops, with the optimality level $V_0=1,0$. The accepted level of optimality corresponds to the maximum amount of water needed to moisten crops, while maintaining soil moisture reserves in their critical phases at the upper limit of optimal moisture content - the lowest moisture capacity ($W_{нв}$).

Table 3. Average long-term values of total evaporation and its difference in the study area, mm

	Period	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**4-10**	**Год**
Brest	1975-2019	54	64	68	71	63	46	31	397	516
	1945-1974	53	62	68	71	63	45	30	392	510
	difference	**1**	**2**	-	-	-	**1**	**1**	**5**	**6**
Pruzhany	1975-2019	52	66	71	75	60	44	28	395	505
	1945-1974	51	63	69	72	59	43	28	384	493
	difference	**1**	**3**	**2**	**3**	**1**	**1**	-	**11**	**12**
Pinsk	1975-2019	55	64	72	72	59	45	31	398	508
	1945-1974	53	62	67	67	56	42	29	376	482
	difference	**2**	**2**	**5**	**5**	**3**	**3**	**2**	**22**	**26**
Ivatsevichi	1975-2019	58	69	73	75	60	44	30	409	521
	1945-1974	55	67	71	72	59	43	29	396	504
	difference	**3**	**2**	**2**	**3**	**1**	**1**	**1**	**13**	**17**
Gantsevich	1975-2019	57	68	73	72	57	42	31	401	525
	1945-1974	56	67	70	67	56	41	31	387	510

	difference	**2**	**2**	**3**	**5**	**1**	**1**	**-**	**14**	**15**
Baranovichi	1975-2019	55	70	75	77	63	45	29	413	515
	1945-1974	53	68	72	72	60	42	28	394	495
	difference	**2**	**2**	**3**	**5**	**3**	**3**	**1**	**19**	**20**

Table 4. Water consumption deficits of 75% supply and their differences in the study area, mm

	Period	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**4-10**
Brest	1975-2019	44	50	47	41	37	25	16	260
	1945-1974	50	56	39	45	35	32	12	269
	difference	**-6**	**-6**	**8**	**-4**	**2**	**-7**	**4**	**-9**
Pruzhany	1975-2019	40	41	37	33	32	15	9	207
	1945-1974	43	47	30	48	20	25	6	219
	difference	**-3**	**-6**	**7**	**-15**	**12**	**-10**	**3**	**-12**
Pinsk	1975-2019	44	50	35	36	44	18	10	237
	1945-1974	51	51	50	46	36	37	5	276
	difference	**-7**	**-1**	**-15**	**-10**	**8**	**-19**	**5**	**-39**
Ivatsevichi	1975-2019	40	47	44	32	46	14	12	235
	1945-1974	45	43	47	41	33	28	3	240
	difference	**-5**	**4**	**-3**	**-9**	**13**	**-14**	**9**	**-5**
Gantsevichi	1975-2019	38	48	25	20	25	7	+6	169
	1945-1974	43	42	40	33	16	17	+3	188
	difference	**-5**	**6**	**-15**	**-13**	**9**	**-10**	**+3**	**-19**
Baranovichi	1975-2019	41	50	31	25	38	14	8	207
	1945-1974	39	47	40	44	35	24	1	230
	difference	**2**	**3**	**-9**	**-19**	**3**	**-10**	**7**	**-23**

As it can be seen from the 4th Table, there has been a decrease in water consumption deficits, on average, about 8% (minimum 2.1% in Ivatsevichi, maximum 14.1% in Pinsk) during the growing season over the last 45 years. The greatest significance is the reduction of deficits in the active phase of crop vegetation (May-July). In total, over this period, water consumption deficits decreased on average in the study area by 16 mm (from 2 mm in Brest to 26 mm in Pinsk), that indicates an approximate reduction in irrigation norms to 18%. In August, there is an increase in water consumption deficits, but at the same time, for most crops, the need for irrigation measures disappears. The calculations performed for other provision and optimality levels, in general, reflect the situation presented in the Table 4.

4. CONCLUSIONS

As a result of the performed research, the statistical significance of changes in the regime of climatic characteristics over the past forty-five years (1975-2019) has been established. In addition to global, planetary processes associated with climate warming, a significant role of anthropogenic factors has been established, in particular, large-scale drainage amelioration, which also influenced the noted changes.

There is a shift in the boundaries of agro-climatic regions according to the conditions of heat supply (the sum of accumulated air temperatures > 10 °C) by about 40-50 km in the northeast-southwest direction. The territory of Belarus began to receive the missing thermal resources, which predetermined the possibility of intensifying agricultural production (introducing new, more moisture-loving and highly productive types of crops into circulation).

The climatic conditions of Belarus are losing the features of continentality due to the smoothing of the annual amplitudes of the studied characteristics (air temperatures, precipitation). The conditions of natural moistening, along with thermal resources, in combination become more favorable and, as a result, reduce the shortage of water consumption for crops. Saving irrigation water during the growing season is about 150-200 m^3/ha, which is a significant value and can affect the reduction of agricultural costs.

An analysis of the trends in the studied characteristics shows that the noted dynamics of natural heat and moisture supply will continue for at least the next thirty years. In this regard, the methods for designing the main elements and structures of amelioration and water management facilities should be adjusted.

Currently, strategically important directions of adaptation to climate change in the field of water amelioration are:

- Modernization and optimization of the amelioration system, taking into account long-term trends in climate change and water use priorities as part of a comprehensive Belarus water management strategy.
- The involvement of river floodplains in economic use, taking into account the likelihood of flooding in the conditions of climate change, informing the population and local authorities about the long-term risk of flooding of floodplain territories and legislatively increasing personal responsibility for their use and insurance of flood damage.
- Organization of prompt notification of the population and local authorities about the danger of floods using modern information technologies.
- Expanding the practice of restoring natural channels and floodplains as an economically and environmentally effective measure of protection against floods and reducing damage from them.
- Transfer to other categories of lands, for which, based on environmental and economic considerations, it is inappropriate to reconstruct amelioration systems and structures.
- Restoration of lands disturbed as a result of large-scale drainage amelioration (reduction of areas with a destroyed fertile layer, the use of forest amelioration to reduce wind erosion, monitoring the status of drained peatlands in fire hazardous periods, etc.).

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DEVELOPMENT OF SUBSURFACE DRAINAGE DESIGN CRITERIA FOR IRRIGATED SUGARCANE IN NORTHERN KWAZULU-NATAL, SOUTH AFRICA

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ABSTRACT

South Africa continues to experience reduced sugarcane yields due to shallow watertables in certain irrigation schemes, both during the winter (irrigation) and summer (rainfall and irrigation) seasons. The problem has not spared irrigation schemes that have been fully-equipped with subsurface drainage systems for controlling shallow watertables. The existing subsurface drainage systems in KwaZulu-Natal, South Africa were designed based on an ad-hoc drainage design criteria (DDC) that was developed more than 35 years ago. In clay soils, the DDC stipulates a design watertable depth (WTD), drain depth (Dl), drain spacing (L) and drainage discharge (DD) combination of 1.2m, 1.8m, 54m and 5mm.day^{-1}, respectively, while in clay-loam soils, the DDC recommends a design WTD, Dl, L, and DD combination of 1.2m, 1.8m, 72m, and 5mm.day^{-1}, respectively. With the continued shallow watertable problem, there is evidently a need to develop new DDC criteria that is responsive to the current drainage needs. We developed a subsurface DDC for irrigated sugarcane in northern KwaZulu-Natal Province, South Africa, using a drainage model (DRAINMOD) that was already calibrated and validated in the area in 2013. The model simulated WTD and DDs for different drainage system scenarios with varied combinations of Dl and L in two soil types of clay and clay-loam. The results suggested that, a recommended design WTD of 1.2m for sugarcane grown in clay-loam soil corresponds with a Dl, L and design DD of 1.4 to 1.8m, 55 to 70m and 2.5 to 4.2mm.day^{-1}, respectively. In clay soils, the results suggested that the same recommended design WTD of 1.2m corresponds with a Dl, L and design DD in the ranges of 1.4 to 1.8m, 25 to 40m, and 2.2 to 5.1mm.day^{-1}, respectively. We conclude that the currently adopted DDC in the two soil types should be revisited to match with the above stipulated combinations of drainage design parameters. Further research should consider (i) field verification of the developed DDC in selected sugarcane fields and (ii) economic impact analysis of installation costs before the DDC can be widely adopted in the KwaZulu-Natal Province. Similarly, the potential impacts of future climate change on drain performance (WTD and DD) need to be investigated to assess the ability of the drainage systems to fulfill their mandates during their life span/cycle under different plausible climate scenarios in the near- and far-future, accordingly.

Keywords: Design standards; climate change; scenarios; South Africa; sustainability.

1. INTRODUCTION

Agrarian history indicates that between 2000 and 4000 BC, the Sumerians deserted their agricultural lands in the valleys of Euphrates and Tigris in the Mesopotamia (Luthin, 1964; Pitman and Lauchli, 2002). According to Jacobsen and Adams (1958), Luthin (1964), Boyden (1987) and Ghassem et al. (1995), this was due to poor drainage, both shallow watertables and salinization, which lowered the crop production potential of the irrigation fields in the area. The global annual rate of desertification due to waterlogging and salinization of agricultural lands is

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currently at 300,000 – 1,500,000 ha (Ojo et al., 2011; Kumar and Sharma, 2020; Harper et al., 2021; Singh, 2022). South Africa is also facing similar problems with nearly 16% of its total irrigated area under waterlogged conditions (Madramootoo et al., 1997; FAO, 2016; Taguta et al., 2022). Recently, Armour and Viljoen (2008) reported the desertification of the Boitumelo vineyards in the Western Cape Province (a 2007 South African government funded project), where poor drainage (salinization) rendered nearly 80% of the initially developed land inappropriate for crop production (Armour and Viljoen, 2008). In this context, Santayana (2005) cautions that "those who ignore lessons from history are doomed to repeat them". The prevailing global rate of desertification due to waterlogging and soil salinization is a clear indication that history is likely to repeat itself, particulary if the drainage problem is not addressed in time.

The need for effective subsurface drainage systems in all irrigated lands cannot be over-emphasized, as it has proven to be the most sustainable and long-term solution to both waterlogging and soil salinization (Smedema et al., 2000; Singh et al., 2006; Noria et al., 2007). Like any other agricultural water management system, success is dependent on how well the systems are designed, installed, operated and maintained. Notably, agricultural drainage systems are meant to prevent the occurance of soil salinization and waterlogging, as opposed to reclaiming already waterlogged or salinized soils (Oosterbaan, 2000; Bastiaanssen et al., 2007). Accordingly, drainage needs must be predicted, based on the excess water being supplied by irrigation, rainfall or seepage. Studies by Manjunatha et al. (2004), Srinivasulu et al. (2004) and Ritzema et al. (2008) clearly show how the lack of a meticulous understanding of the interaction among recharge, watertable depth and subsurface drainage systems have resulted in ad-hoc adjustment of subsurface drainage design parameters (drain depth, spacing and design discharge), in the search for more accurate and optimum design parameters. Conversely, drainage installation costs have also increased significantly (Ritzema and Shultz, 2010), and it is not economical, both in terms of time and money, to design drainage systems using a trial and error approach or physically conducting new drainage experiments by installing drains at varied drain depths and spacing (ASAE, 1999).

The advent of drainage simulation models in the 1970's has enabled drainage engineers to perform thorough analyses of the functionality of various subsurface drainage system design parameter combinations prior to system installation (Bastiaanssen et al., 2007, Malota et al., 2022). For example, the application of the DRAINMOD model (Skaggs, 1978), the WaSim model (Hess et al., 2000) and the SaltMOD model (Oosterbaan, 2000), among others, in Australia (Yang, 2008), India (Hirekhan et al., 2007) and Turkey (Bahceci et al., 2006), have all facilited the timely and effective determination of optimal subsurface drainage system parameters. In South Africa, particulary in KwaZulu-Natal Province, the existing subsurface drainage systems were designed based on an ad-hoc drainage criteria more than 35 years ago. Despite this, shallow watertable problems are still being experience in many irrigation schemes where sugarcane is being grown. There is evidently a need to develop new subsurface drainage design criteria to cope with current drainage needs. Most importantly, irrigation, rainfall and drainage are all inter-related and therefore need to be managed as a whole. The objective of this study was to develop subsurface drainage design criteria for irrigated sugarcane in northern KwaZulu-Natal Province, South Africa.

2. METHODS

2.1 Description of the study site

This study was conducted on a 32 ha irrigated sugarcane field in Pongola, KwaZulu-Natal Province, South Africa (27° 23' 0" South and 31° 37' 0" East). The dominant soils at the site are clay and clay-loam soils (van der Merwe, 2003). During the winter months of April to October, crop production is through irrigation, whereas during the summer months of November to March, crop production is normally through both irrigation and rainfall. Initially, the site relied on natural drainage, which was later found to be ineffective in controlling shallow watertables. This led to the installation of the first artificial subsurface drainage at the site in 1995. However, shallow watertables were still affecting sugarcane growth, and this led to the reinstallation of another subsurface drainage system in 2003 with a reduced drain spacing of 72m in clay-loam soils, and 54m in clay soils, while the drain depth was maintained at 1.8m. The drainage system was designed to maintain a design watertable depth of 1.2m from the soil surface. Figure 1 presents details of the existing subsurface drainage system during installation in 2003.

Figure 1. Details of the existing susbsurface draianage system ((a) excavation of trenches at the required depth, (b) installation of perforated subsurface drain pipes, and (c) a collector drain pipe discharging into an open drain)

2.2 Simulation of subsurface drainage scenarios in two different soil types at the site

This study used the DRAINMOD model (Skaggs 1978), a subsurface drainage model that was already calibrated and validated to simulate watertable depths (WTDs) and drainage discharges (DDs) at the site (see Malota and Senzanje, 2013; Malota and Senzanje, 2015). DRAINMOD predicts watertable depths (WTDs) (m) and drainage discharges (DDs) (mm.day^{-1}) using the stead-state Hooghoudt equation (see Smederma and Rycroft, 1983 for details). Subsurface drainage scenarios with varied combinations of drain depth and spacing were simulated to represent two soil types (clay and clay-loam) that are dominant at the study site. Input parameters were saturated hydraulic conductivity values for each soil type (K_{sat}) (i.e. K_{sat} = 0.24m.day^{-1} for clay, and 0.60m.day^{-1} for clay-loam soil), thicknesses of the soil profile layers at the site, soil water retention values for each soil type, type of crop (sugarcane), sugarcane crop root elongation (m) with respect to time (days), and weather data (Sepember 2011 – February 2012). K_{sat} values were determined using the auger-hole pumping test (Malota and Senzanje, 2013), while soil water retention values were determined using the pressure plate apparatus (Malota et al., 2022). Thicknesses of the soil profile layers were determined from five trentches that were dug in the field. Weather data were in form of rainfall, temeperature, and potential evapotranspiration. Rainfall data were collected at the site using rainguages that were installed across the field, while temperature data were obtained from South African Sugarcane Research Institute (SASRI) weather station located about 3Km from the irrigation scheme. Potential evapotranspiration were calculated using the Thorthwaite equation (Malota and Senzanje, 2015). Full details of these input parameters can be found in Malota and Senzanje (2013), and Malota and Senzanje (2015).

Simulations of subsurface drainage scenarios in clay soil were run with drain depths ranging from 1.4 to 1.8 m and drain spacing from 25 to 40 m at 3 m intervals, whereas for clay-loam soil, simulation scenarios were run at drain depths ranging from 1.4 to 1.8 m, and drain spacing from 55 to 70 m. The selection of this range of drain depth and spacing for simulation was based on a drain depth and spacing guide for KwaZulu-Natal developed by Russell and van der Merwe (1997) and those recommended by Fausey (2005), FAO (2007), Reinders et al. (2016), and Vlotman et al. (2020). For every simulation scenario, the mean WTD and DD were computed and were presented graphically.

3. RESULTS

The calibrated DRAINMOD model simulated WTDs and DDs for subsurface drainage systems with varied drain depth and spacing combinations installed in clay and clay-loam soils. The results of mean simulated WTDs and their respective mean DDs at various combinations of drain depth and spacing in the two soil types are presented in Figures 2 and 3. It is evident from the results (Figure 2a and b) that, when considering a constant drain depth, mean WTDs below the soil surface increased with decreasing drain spacing, and vice versa. For instance, in clay soil (Figure 2a), it can be seen that for a subsurface drainage system installed at a drain depth of 1.4m and its corresponding drain spacing of 40m, the system established a mean WTD of 1.0m. However, at the same 1.4 m drain depth, the system established a mean WTD of 1.11 m, when the drain pipes were installed at a closer spacing of 25m.

Furthermore, the results in Figure 2a show that considering drain pipes installed in clay soil at drain depth ranging from 1.4 to 1.8m, mean WTDs between 1.0 and 1.5m were established with the drain pipes installed at a spacing ranging from 25 to 40m. On the other hand (Figure 2b), by installing drain pipes at the same 1.4 to 1.8m drain depth, mean WTDs between 1.0 and 1.5m were established in clay-loam soil with drain pipes installed at a relatively wider spacing, ranging from 55 to 70m.

Results of mean DDs at various combinations of drain depth and spacing in Figure 3a and b show that when the drain depth was kept constant in both clay and clay-loam soils, mean DDs increased with decreasing drain spacing and vice versa. Furthermore, it can be seen in Figure 3a and b that, generally, mean DDs increase with increasing drain depth when drain spacing and type of soil were kept constant.

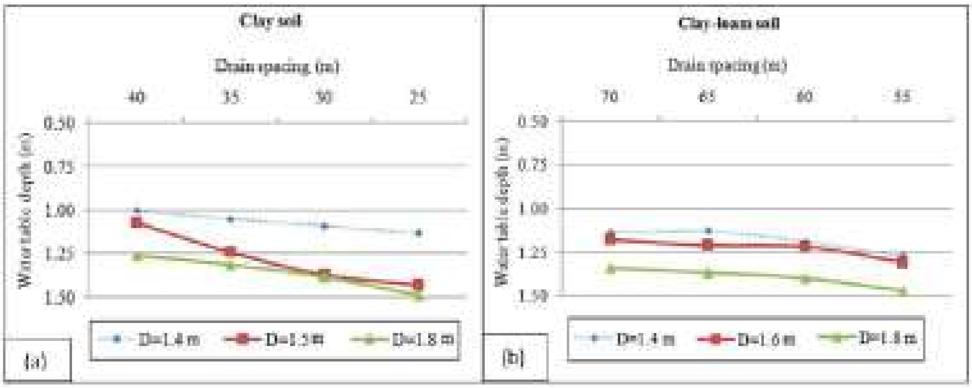

Figure 2. Mean watertable depths in clay and clay-loam soils simulated at different drain depth (D) and spacing combinations

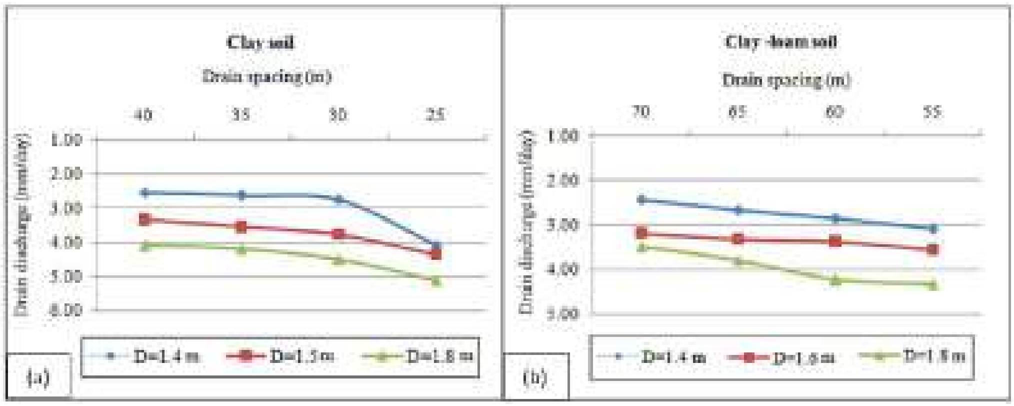

Figure 3. Mean drainage discharges in clay and clay-loam soils simulated at different depth and spacing combinations

4. DISCUSSION

The design of subsurface drainage systems for crop production systems involves appropriate determination of drain depth, spacing and drainage discharge in relation to a particular type of soil and crop (Hooghoudt, 1940). Results of mean simulated WTDs and DDs confirmed the prevailing designs of installing drain pipes at shallow depths, in order to establish water WTDs near the soil surface and vice versa. The possible explanation to this water table behavior could be due to differences in hydraulic heads at mid-drain spacing. The hydraulic head, according to Dagan (1964), has a direct effect on both WTD at mid-drain spacing and drain discharge at drain outlet points. However, considering a constant drain depth and soil type, in as far as establishing deeper WTD is concerned, installing drain pipes at a closer spacing appeared to be a better option, as this resulted in deeper mean WTDs. This was attributed to the elliptical water table shape with a very steep cone of depression, which according to Rimidis and Dierickx (2003), increases the drain flux towards the drain pipe, hence the high water table draw down (Δh) at mid-drain spacing and the increased drainage discharges (mm.day^{-1}).

Analysis of mean WTDs at various combinations of drain depth and spacing in clay and clay-loam soils suggested that closer drain spacing in clay soil and wider drain spacing in clay-loam soils are more likely to establish the same mean seasonal WTD when drain depth is kept constant in both soil types. This was explained by differences in K_{sat} values for the two soil types, corroborating the description behind the Hooghoudt drain spacing equation, which states that the square of drain spacing is directly proportional to the equivalent depth and inversely proportional to the drain discharge (Hooghoudt, 1940). Further to that, according to Oosterbaan (2000), the decrease in drain spacing can result in an increase in groundwater flow towards subsurface drain pipes, which also results in an instantaneous increase in approach flow resistance near the drain pipe. Consequently, this also causes an instatenous rise in WTD at mid-drain spacing, which according to Oosterbaan (2000) only lasts for a few hours. Thus, a mean WTD that generally corresponds with a drainage system whose drains are installed at a wider spacing can be achieved even when drain pipes are installed closely.

In a study of a similar nature conducted in the Southern part of Louisiana, USA, Carter and Camp (1994) found out that by considering the same type of soil and a constant drain depth, shallow WTDs are established when drain pipes are installed at a wider spacing, while deeper WTDs are established when drain pipes are installed at a closer spacing. On the other hand, in Southeast Queensland, Australia, Cook and Rassan (2002) found that considering a subsurface drainage system with drain pipes installed at the same drain depth in two soil types with different K_{sat} values, the same WTD can be established in both soil types, but with drain pipes installed at a wider spacing in the soil with a higher K_{sat} value, and vice versa.

FAO (2007) highlights that the use of Hooghoudt equation in developing drainage design criteria for arid and semi-arid conditions is based on a mean seasonal WTD and drainage discharge. Thus, it is apparent that under these climatic conditions the application of the Hooghoudt equation is not entirely based on a steady-state criterion, but a dynamic equilibrium WTD and DD (Oosterbaan, 2000). It therefore follows that based on the simulation results obtained in this study, respective drain depth, spacing and drainage discharge in the ranges of 1.4 to 1.8m, 55 to 70m and 2.5 to 4.2mm.day^{-1}, would be appropriate to ensure safe mean WTD of 1.2m depth for sugarcane grown in clay-loam soil. On the other hand, for sugarcane grown in clay soil, respective drain depth, spacing and drainage discharge in the ranges of 1.4 to 1.8m, 25 to 40m and 2.5 to 5.1mm.day^{-1} appeared to be appropriate in ensuring a mean WTD 1.2m from the soil surface.

The final selection of drain depth and spacing combination to be adopted at the site should be considered with caution, by making sure that drainage measures are not taken aggressively. Installation costs and available installation equipment in the area must be taken into consideration. In addition, efforts must also aim at selecting a drain depth and spacing combination that would considerably reduce irrigation water requirements by optimizing on the soil moisture contribution to the root zone depth in the form of groundwater contribution.

5. CONCLUSIONS AND RECOMMENDATIONS

A detailed analysis of simulated WTDs and DDs at various drain depths and spacing combinations supported the generally prevailing idea of designing and installing drain pipes at a closer spacing in soils with low K_{sat} values, and wider drain spacing in soils with high K_{sat} values. Thus, in order to maintain a safe WTD of 1.2 for surgarcane grown in clay-loam soils, the currently adopted drainage design criteria should be revisted to stipulate a drain spacing, depth, and discharge that ranges from 55 to 70m, from 1.4 to 1.8m, and 2.5 to 4.2mm.day^{-1}, respectively. Similarly, in clay soils, a drainage design criteria that aims at maintaining the same mean WTD of 1.2m should also be revisted to stipulate a drain spacing, drain depth, and drainage discharge that ranges from 25 to 40m, 1.4 to 1.8m, and 2.5 to 5.1mm.day^{-1}, respectively. Nevertheless, we recommend field verification of the developed drainage design criteria in selected sugarcane fields before they can be widely adopted in the KwaZulu-Natal Province. Further to that, the potential impacts of future climate change on drain performance need to be investigated to assess the ability of existing drainage systems to fulfill their mandate during their life span/cycle under different plausible climate scenarios in the near- and far-future, accordingly.

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DRAINAGE OF IRRIGATED AGRICULTURE IN BIHAR (INDIA) - SOME ISSUES

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ABSTRACT

Irrigation development has been taking place for centuries in India. Considerable areas of fertile land under irrigated agriculture have gone out of production due to waterlogging and salt-related problems. The provision of drainage channels was differed or postponed in several projects due to shortage of funds during the initial stages. Due to this the productivity of water (t/ha/mm) in India remains very low. The main reason for the low yields is improper water management, especially lack of drainage in irrigated command areas. There are vast areas in the country urgently requiring drainage works and the present governmental resources are not adequate to cope up the growing demand. Promotion of the private sector in reclamation work and installation of sub-surface drains at local level needs encouragement. All these issues together with the research activities inclusive of drainage materials undertaken by different organizations have been critically described and discussed in this paper.

Keywords : Irrigated Agriculture ; Waterlogging and Salinity ; Drainage Coefficient ; Drainage Materials ; Spacing of Subsurface Drains.

1. INTRODUCTION

In India, development activities in irrigation have been taking place for centuries. Rivers played a central role in the life and living of people and consequently their civilizations came to be known as 'river valley civilizations'. Even during Vedic period (4000 BC) there is ample evidence of wide use of irrigation from dug wells or inundated water. The disappearance of Harappan civilization (2500 BC-1700 BC) was earlier attributed to the invasion of Aryans. This view, however, is now disputed and relatively recent investigations have established that even before the Aryans came, the decay of this civilization had started on account of internal factors, mostly related to water resources. These factors included increased salinity of land due to indiscriminate use of irrigation water, change of river courses and occurrence of floods. On the basis of archaeological evidence, experts now believe that the city of Mohenjo-Daro was battered by several reoccurrence of devastating floods (Roy, 1999).

Land and water have been vital causative factors behind any civilization. There is a kind of truism which deserves repetition. Wherever the two, land and water have come together, human civilizations have taken root. The earlier civilizations whether of the fertile crescent, the Indo- Gangetic plain or of China were induced to appear and to develop because of the advantageous conjugation of land and water (Roy, 1998).

As the major tracts in the Indus basin have become parts of Pakistan at the time of partition, India had no option but to launch a focused action to ensure well-conceived planning process. When India got independence in 1947, its prime aim was economic reconstruction, which could only be achieved through increasing the productivity of its culturable lands as the scope for increasing the extent of culturable land was very limited. India could thus achieve irrigation potential increase at the rate of 2.6 to 2.8 million hectares per year. This was the highest rate of development achieved by any country in the world. India supports nearly 18 % of the population of the world and 15% of the live stocks of the world on merely 2.4% of the world’s geographical area (Bhattacharya et al., 2015). Currently the number of medium and major irrigation scheme in India is more than 1250. India’s total cultivable area is 183.6 Mha, of which net and gross sown areas are 141 and 190 Mha respectively. Food grain production has increased by about 5.5 times, from merely 50 million tons in 1950 to 275 tons in 2017 making India not only self-sufficient but a net exporter of food grains (Kumar and Sharma, 2020).

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Agriculture continues to dominate the Indian economy with the gross domestic product contributing about 23% to the gross domestic product of the country.

Although the mean annual rainfall for the country is about 1170 mm, there is an extreme spatial and temporal variation. Rainfall is very intense during three to four months i.e. mid-June to mid-October. During this period surface drainage is needed to overcome temporary or prolonged inundation of agricultural lands. The total annual surface flow of water in the country is assessed as 176 Mha-m, 67 Mha-m is utilizable and can be harnessed to irrigation. Moreover, approximately 27.5 Mha-m is annual recharge from rainfall and seepage and hence available as ground water resource. Thus, water resource on an aggregate basis is not a constraint for desired irrigation expansion.

Drainage systems have many benefits and also positive socio-economic inputs i.e. increase in crop yield (20-25 %), in cropping intensity (30-60%), increase in employment, reduced migration to urban areas, increase in land value and development of agro-industries. A state-wise break-up of waterlogged area is as given in Table-1. Also, the area under salt-affected soils has been given in Table-1 and Fig-1. Some of the above issues including steps taken to reclaim the waterlogged and saline area and training and research activities are described discussed in this paper.

2. Agriculture, Population, and Irrigation

Agriculture occupies the prime position in Indian economy because of its share to overall economic growth through supply of food and raw materials. It is a source of livelihood for the majority of population (70% for India and 90% for Bihar) and provides a large market for non-agricultural goods and services. It has often been observed that Indian economy fluctuates with the agricultural production in the country. The rate of growth of population in India is slightly over 2% per annum and considering that unlike the conditions prevailing in high income countries, food grains, edible oil and sugar absorb a lion's share of household income in India. The increasing demand for these food articles has to be met with enhanced production, say of the order of 2.5% for cereals and 3 to 4 % for pulses, edible oil, and sugar. For a country of continental dimensions like India, food import as against self-sufficiency ought to be ruled out. This situation naturally gives rise to a need for planning optimal crop production across the states within the Indian union.

3. Appraisal of the problem of waterlogging in the country

During 1975 and 1980, rapid appraisal of 24 major and medium canal irrigation systems were conducted by Central Water Commission, Govt. of India. In its final report it was stated that 19 out of 24 cases were recorded for the single item, i. e. 'Inadequate Drainage System and Waterlogging', drainage and waterlogging being treated as the same subject as given in Table-2. In 22 out of 24 cases excessive seepage and need for its determination and canal lining are the principal features. In this Table item no 5, 8, 9 and 16 indicate the urgent need for drainage in irrigated agriculture (CWC, 1980). Consequently, stress was given on effective management of existing irrigation systems than on further creation of irrigation potential. However, it was also argued that water resources development activities cannot be ignored just because there could be some environmental problems. Such adverse effects can be considered well in advance and remedial measures be taken as required.

4. Criteria for Waterlogging

Each state has its own norms of waterlogging as given in Table-3. There is no updated data regarding drainage problem in the country. The estimates vary from 3.95 to 16 Mha of waterlogged areas and from 3.3 to 10.9 Mha of saline area (Bhattacharya and Michael, 2003). There are two types of waterlogging e. g. Seasonal waterlogging (April to November) and perpetual waterlogging (persists during all the seasons).

Table 1 State-Wise Distribution of Waterlogged Area in India (Bhargava 1998)

State	Waterlogged Area (in '000 ha)	Salt affected Area (in '000 ha)
Punjab	1090	404
Haryana	620	526
UP	810	1295
Bihar	117	4
Rajasthan	348	728
Gujrat	484	1214
M. P.	57	242
Karnataka	10	404
A. P. (inclusive of Telangana)	111	240
Maharashtra	339	534
West Bengal	1850	850
Orissa	60	688
Tamil Nadu	18	4
Kerala	61	16
Delhi	1	16
Jammu and Kashmir	10	-
Total :	**5.986 ≈ 6 million ha**	**7.165 ≈ 7 million ha**

Fig. 1 Salt affected soils in India (Source CSSRI, Karnal, 1986)

Table 2 Deficiencies in Projects on Water Utilization Source: CWC (1980) and WALMI (1989)

S. No	Deficiencies in Irrigation Projects	Number of deficient projects out of 25
1.	Reappraisal of available surface and return flow from Irrigation	16
2.	Pumping of irrigation water and its effects	2
3.	Silting of reservoirs, conducting sedimentation surveys and measures to prevent silting	11
4.	Insufficient number of hydrological and meteorological stations in command and catchment areas	4
5.	Excessive seepage and need for determining it. Lining of canal is required	22

S. No	Deficiencies in Irrigation Projects	Number of deficient projects out of 25
6.	Tail reaches do not get enough irrigation water	5*
7.	Absence of conjunctive use of ground and surface water	18
8.	Inadequate drainage system and waterlogging	19
9.	Salinity in soils and ground water	7
10.	Bad maintenance of canal system	19
11.	Improper operation of reservoir and canal system	10
12.	Canal cannot carry design discharge	5
13.	Insufficient canal structures and their improper maintenance	13
14.	Lack of communication facilities in the command	12
15.	Lack of field channels and proper maintenance	11
16.	Improper water management Agronomy	25
17.	Improper cropping calendar and cropping pattern	23
18.	Lack of research to determine the water requirement of crops	12
19.	Lack of research to determine suitable types of crops to suit thesoils in the command	17
20.	Poor extension services, lack of pilot projects, demonstration farms, etc.	20
21.	Lack of detailed soil surveys of command areas	16
22.	Excessive application of irrigation water to crops	10

Table-3 Norms For Categorization of Waterlogged Areas in India (Navalawala, 1991)

SL. no.	Name of the state and criteria	Water table depth below ground level (m)
1.	**UP. (Sharda Sahayak project)**	
	Worst zone	<1
	Bad zone	1 – 2
	Alarming zone	2 – 3
	Sale zone	>3
2.	**Punjab**	
	Very Critical	0 – 15
	Critical	0 – 2.0
3.	**Haryana**	
	Critical Waterlogged	0 – 1.5
	Critical	1.5 – 3
4.	Karnataka (Tungabhadra Command)	0 – 2
5.	Himachal Pradesh	0 – 2
6.	Maharashtra	
	Fully water logged	Water at ground Surface
	Waterlogged	0 – 1.2

5. Waterlogging and CAD Programme

For major and medium projects, the gap between irrigation potential created and that being utilized is maximum for the status of Maharashtra(40.6%) and Gujarat (43.99%) and minimum for states like undivided Andhra Pradesh (0.97%) and Tamil Nadu (0.12%) and there is no lag in the case of states like Punjab, Odisha, and West Bengal (WALMI,1989).Therefore, one of the most important steps to enhance the agricultural production is the Command Area Development Programme (CAD), which is sponsored by the central Governments with equal participation of the State Governments. The important activities of CAD programme are: construction of field channels including its lining in vulnerable reaches, land shaping and land grading, systematic programme of land consolidation, farm roads, field drains and intermediate drains. Much emphasis has been given to the construction of field drains and intermediate drains. Therefore, yields are supposed to improve through better soil and water management practices besides other measures e. g. credits, marketing facilities etc. In some command areas surface ditches of 2.0 m depth have been constructed to serve both as a surface drain and subsurface drain.

An observable decline in waterlogged and saline-affected regions within the command area of major and medium schemes has been noted in contrast to the findings of the Working Group Report by the Ministry of Water Resources, Government of India (1991). This reduction can be partly attributed to the successful execution of on-farm development (OFD) within various command area development (CAD) initiatives. From the year 2004, through the restructured Command Area Development and Water Management (CADWM) program, the central government revised the funding amount to Rs 15,000/- per hectare for surface and bio-drainage systems, and Rs 40,000/- per hectare for subsurface drainage systems. The cost distribution follows a 50:40:10 ratio among the central government, state governments, and the farmers, respectively. Under the 'Centrally Sponsored CAD Program,' approximately 57,123 hectares across 446 irrigation schemes in nine states were sanctioned for reclamation, with 44,135 hectares having been reclaimed by the Ministry of Water Resources by 2004 (MoWR, 2007). Recent data indicates a nationwide reclamation of around 1.39 million hectares, encompassing 1.3 million hectares of sodic soils, 0.04 million hectares of saline-sodic soils, and 0.05 million hectares of waterlogged soils (Singh, 2007).

6. Bio-drainage

Numerous field-oriented research initiatives focusing on agricultural land drainage and reclamation have been undertaken in collaboration with the governments of the Netherlands and Canada, as well as the World Bank, across various states including Rajasthan, Haryana, Gujarat, Karnataka, undivided Andhra Pradesh, and Uttar Pradesh. These efforts are based on practical investigations aimed at addressing drainage challenges. Additionally, the concept of "bio-drainage," involving the utilization of water-intensive trees to draw down groundwater levels, has been identified as a strategy within this context.

The use of quick growing plants (exotic trees) is utilized to improve marshy and waterlogged lands. It is because such plants draw water at a faster rate. This system requires thorough investigations on plant species to suit a particular area particularly in saline soils. This concept was adopted as an effective measure for controlling waterlogging in Indira Gandhi Nahar Pariyojana (IGNP) in Rajasthan (Kapoor, 1998).

7. Flood, Waterlogging and Environment

Flood and drainage stand as pivotal, interconnected challenges within the poor state, particularly in North Bihar, where the drainage of the North Bihar plains is orchestrated by Himalayan rivers, primarily the Ganga acting as the main drain. These rivers, sourced from both rain and snow, exhibit a continuous flow. Prominent among North Bihar's rivers are the Kosi, Gandak, Baghmati, Burhi Gandak, Kamla, Kamla-Balan, Mahananda, Kareh, and several others. These rivers possess relatively youthful terrain features and are actively involved in deepening their channels. Running parallel to the Ganga in a south-eastward direction, they eventually converge with it. Characterized by monsoonal patterns, North Bihar experiences rainfall with considerable temporal and spatial variations, concentrated over a few months i.e., from mid-June to mid-October.

This inconsistent rainfall distribution perpetuates frequent floods, resulting in substantial crop losses and the annual inundation of extensive areas. Hence, flood and drainage persist as vital issues within the state, chiefly stemming from intense and unpredictable precipitation coupled with insufficient drainage systems.

It is the universal fallacy of a common man that ‘If a little of something is good, then more of it must be better'. In irrigation just the optimum is the best, no less and certainly not more. Excess irrigation water may result into waterlogging and its allied problems. Lack of drainage facility is probably the cause of failure of many irrigation works in the past. Increase in salinity in various irrigation projects all over the world was found to be due to lack of proper provision of drainage. While the canal network is planned on a watershed basis and is provided with inspection roads or paths, the drains are situated away from the track of inspection. Often drains are not situated where inspecting staff normally go on tour.

Therefore, the conditions of drains remain less known to the irrigation personnel resulting in their poor maintenance. Thus, the water table slowly rises, and salt problems are created. Production goes down and ultimately the area becomes waterlogged and goes out of production. For the prevention of environmental degradation various laws have been enacted by the States and Central Government of India. These acts relate not only to water resources projects but to other aspects of environmental decline also, the Environmental Protection Act, 1986 of Government of India being the latest and most comprehensive one.

8. Sub-surface Drain Spacing and Depth

The drain depth is reckoned from the ground surface to the bottom of the tile. The deeper the drain, the more is the drainable area per drain line and farther is the spacing of the drains. The drains are closely spaced in clay soils and far apart in sandy soils. IS10907-1984 recommended drains placed about 1.25 m as given in Table-1.

T**abl1**-1 Drain's Spacing for Humid Areas

Type of Soil	Hydraulic Conductivity of soils	Drain Spacing (m)
Clay and clay loam	Very slow (k<1.3 mm/hr)	9.0-21.5
Silt and silty clay loam	Slow to moderately slow (k =1.3-2 mm/hr)	18.5 to 30.5
Sandy loam	Moderate to rapid (20-25 mm/hr)	30.5 to 91.5

9. Vertical Drainage

In canal irrigation areas, because of continuous and intensive application of surface irrigation, the subsoil water table rises up resulting in waterlogging and salinity hazards. These can be prevented by withdrawing water from groundwater also, which will lower the water table and reduce the soil salinity and waterlogging hazards. In areas where ground water is brackish and has been rising fast upward, conjunctive use of surface and ground has special importance. The upward rising trend of saline ground water can be controlled by installing augmentation tube wells and the saline water can be mixed with canal water for making its use for irrigation. In any tube well drainage scheme, the following aspects of water quality vis-à-vis depth is considered:

- In order to find out the aquifers to be tapped, investigations in respect of depth of aquifer and water quality are carried out by extensively covering the project area.
- If the water quality varies with depth, only those aquifers which are having good quality water are tapped, provided these aquifers are connected to water table.

In case freshwater floats over saline water, installation of skimming wells is preferred. Vertical drainage has been provided with the installation of shallow tube wells in some of the command areas of India. Thus, the conjunctive use of ground and surface water is practiced to form a dynamic equilibrium condition i.e. to maintain the constant depth of water table. Where the ground water is saline, mixing it with good quality surface water has also been tried successfully. A few examples are as described below:

The Gandak irrigation project is an international major irrigation and power project involving Bihar and UP states of India and adjacent portion of Nepal. In the eastern UP portion of the project, irrigation was first started in 1971. The depth of the groundwater table was high i.e. 3 to 4 m below ground surface and showed a further sign of rise. Therefore, a surface drainage system was planned in the area, but very few field drains could be constructed due to extremely small sizes of land holdings. Hence, it was decided to have vertical drainage system in the area to control the rise of ground water table consisting of 2000 such tube wells. Since the ground water is of good quality, the water from these tube wells is used for irrigation (Western Gandak Canal Project Report, 1986).

In the state of Haryana which is situated in the semi-arid /arid zone of the country, the ground water is brackish. Therefore, a system of skimming wells has been tried with good results. Water pumped out from these skimming wells are mixed with canal water and used for irrigation. Similar efforts have been made in Punjab also (WTC, 1987).

10. Drainage Materials and Machinery

India has its own well-developed industry for manufacturing agricultural tractors and other equipment. Annual production of tractors (15 to 50 H. P.) has already exceeded ten lakhs. Heavy machines used for construction of drainage works e.g., crawler tractors, excavators, back-hoes, draglines, and trenchers are also manufactured in the country. Tile drains of both clay and concrete are available almost everywhere in the country. Plastic pipes with perforations are also manufactured in the sizes of 25-200 mm. Recently, the manufacturing of perforated corrugated polyvinyl chloride (PVC) pipes has also been started in India. All these manufactured materials are standardized by the National Bureau of Standard (NBS) which is an autonomous body in the country with the primary responsibility of framing standards and specifications for all kinds of goods and products.

11. Research Efforts in Drainage

The need for drainage in the present context was realized as early as 1865 when for the first time the then Government of Punjab drew the attention of the then Governor General to the seriousness of the problem of reh and usar in the canal commands. In 1876, the problem of soil salinity was reported from Uttar Pradesh and at about the same time from Nira canal command in Maharashtra. Alarmed by the exodus of population from Amritsar (Punjab), a tube well drainage experiment was started with 16 tube wells of 0.0425 cumecs capacity each. Experiments were also laid out on tile/pipe drains in Maharashtra and Punjab. Comprehensive work on drainage was carried out as per the requirements of different crops in Maharashtra leading to compilation of observations and design techniques in the Technical Report No. 56 submitted to Maharashtra Government in 1937. The report is still referred to for drainage design in the state.

High costs and low returns often cause a lack of farmers' intent in drainage. Therefore, to make it appealing to the policymakers as well as to the ultimate users, the activities in research should be consistent with the national development goals and should provide results that are relevant to the socio-economic conditions of the users. This constraint suggests that the major emphasis should be on applied research, which is easily adaptable to ongoing development programs. However, basic research should be continued as it provides continuous input to applied research and may indicate solutions to many problems identified in the field.

A subsurface drainage research Institute functioned at Ibban (now in Pakistan). The Royal Commission on Agriculture (1928) mentioned "Now lessons have been learnt and in all future irrigation projects, drainage will form an essential component". However, observations were mainly confined to papers and irrigation projects continued to be commissioned without proper provisions of drainage, even after independence. The concept of irrigation and drainage to go together was religiously emphasized by the second National Irrigation Commission (1972) and National Commission on Agriculture (1976) in India. Several surface drainage schemes in existing irrigation projects were laid out mainly as flood control measures and they provided some relief to agricultural lands. Because of realization of on the part of the agricultural scientists that farm drainage and subsurface drainage will play an important role in the solution of problems related to waterlogging and soil salinity, large number of small scale experiments were carried out by various institutions throughout India as described below.

The major research efforts on agricultural drainage are being made through the state agricultural universities, various research institutions under the Indian Council of Agricultural Research (ICAR), various state training institutes i.e. water and land management institutes (WALMIs) and irrigation management training institutes (IMTIS) etc. Some of the important topics of research on drainage are:

- Tolerance of various crop varieties including paddy to submergence and high water table conditions.
- Estimation of drainage coefficient for different areas and crops. Gupta et al. (1971) developed drainage coefficients for surface drains for different parts of the country.
- Subsurface drainage design criteria (CSSRI, 1986)
- On farm drainage methods to meet the requirements of different crops (Rajput, 1986)

- Reuse of drainage water for irrigation paddy
- Studies on leaching of salts.

Central Soil Salinity Research Institute (CSSRI) at Karnal in Haryana is a premier research institute under ICAR. The output of research at this Institute has led to the development of effective and economically viable technologies for the management of salt affected soils. CSSRI is also carrying out research for design criteria for the tile drainage system and its effects on crop yields. Some of the results are as given in Table-4.

Studies were carried out on an experimental basis to develop design criteria of subsurface drains at Punjab Agricultural University, Ludhiana in 1966. At Jawaharlal Nehru KrishiVishwa Vidyalaya (JNKVV). Indore, experiments were carried out in 1970-71 to examine the effect of sub-surface drains by installing two tile lines of 10 cm diameter and 30 cm long semi-glazed stone tiles at a depth of 1.0 m and a spacing of 14.0 m. At Pant Nagar in Uttara Khand., studies were conducted in 1972 for finding out the proper spacing of tile drains (between 15 m to 35 m) and to develop the design criteria for transient state condition. Similar works have been done and are under progress at many other state agricultural universities (Chauhan, 1988).

Table-4 Crop yields for different pipe Drain spacing's (CSSRI, 1986)

Spacing of Drains (m)	Crop Yield (t/ha)				
	Sorghum	Mustard	Barley	Wheat	Cotton
25.0	0.8	2.4	4.2	4.9	1.8
50.0	0.7	2.0	2.9	4.0	1.6
75.0	0.4	0.9	2.0	2.5	1.6

11.1 RAJAD project (1995, 2001)

The RAJAD project constitutes applied research focusing on the application of horizontal subsurface drains (SSD) and correlated water management methodologies to effectively address the issues of soil salinity and waterlogging in the irrigated command area. Distinguished by its unprecedented scale and comprehensiveness, the project represents a pioneering initiative. Its overarching objective involves the integration of both surface and subsurface drainage with Enhanced Water and Agricultural Management (EWAM), aimed at revitalizing agricultural productivity in the area. Notably, a recurrent observation is the swifter completion of the irrigation facet in contrast to the lingering progress of the drainage component, despite concurrent planning. Valuable insights emanating from field investigations, deliberations in national and international workshops, seminars, technical analyses, and guidelines have provided noteworthy recommendations, necessitating a methodical undertaking of their implementation. Furthermore, the well-recognized hesitation of landowners to allocate land for surface drain construction underscores the need for tailored compensatory measures and equitable cost-sharing among the system beneficiaries. Nonetheless, the primary challenge resides in reducing the expense associated with sub-surface drain (SSD) installation, rendering it financially appealing to Indian farmers who are constrained to minimal investments while expecting favourable returns. This can be ensured by an inclusive participatory approach in the operation and maintenance of completed drainage systems.

12. Training Activities

India has developed a very comprehensive programme for in service training on different aspects of irrigation e.g. operation, maintenance, monitoring, soil and water management including drainage. State Training Institutes (STIs), which includes WALMIs and IMTIs have been established in 14 states with the support provided by World Bank and United States Agency for International Development (USAID). These Institutes offer training to in service personnel of Irrigation Departments. Courses on surface and subsurface drainage aspects are integral parts of these training programmes. In 1988, under USAID supported programme, the Irrigation management and Training project (IMTP, 1988) prepared a Handbook on Drainage of Irrigated Areas in India' which is being used by State Training Institutes and many other institutes of higher learning for their teaching and training programmes.

13. Conclusions

From the above discussion, it can be concluded that flood and drainage are the two vital problems of the country especially the plains of North Bihar. Waterlogging is the retention of areas under water for a considerable period, causing severe damage or complete los s of crop.Both irrigation and drainage have to play very important role in protecting and stabilizing agricultural production in the country. The policy all along has been to provide protective irrigation. Due to improper and inefficient use of irrigation water, sizeable areas are losing productivity due to waterlogging and salt-related problems. Therefore, the importance of drainage in irrigated agriculture is imperative to relieve the conditions. However due to the zeal to create more and more irrigation potential, the due attention was not given to the drainage aspects of agriculture. This resulted in waterlogging and salinity problems in many irrigated command areas.

Important factors which increase agricultural production in irrigated areas are proper soil and water management, quality seeds, application of fertilizers and other chemicals, credit, marketing, communication, and extension. Of all these factors water management is vital. Poor water management results not only in lower yields but also in wastage of scarce water and creates waterlogging conditions and salt related problems. Land grading in combination with a surface drainage system provides adequate surface drainage protection.

India has made planned and concerted efforts in the post-independence era to improve crop yields in its irrigated areas by improving drainage systems and adopting better water and land management practices. These efforts are through the concept of command area development programmes (CAD). In the new projects, adequate financial provisions are made for the drainage works so as to obtain sustained production. All the above efforts are being well supported with very comprehensive and integrated research activities through Indian Council of Agricultural Research (ICAR) and other state Agricultural Universities. A well-coordinated training programme has also been established with the assistance of the World Bank and USAID. Indian industry is quite capable to provide materials and machinery of good quality and standard required for drainage construction.

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DRAINANGE STATUS IN SOUTHERN ZAMBIA WITH CASE STUDIES OF MAZABUKA AND CHIKANKATA DISTRICTS

Davies Mulenga Sampa[1]

ABSTRACT

Zambia is a landlocked country with a total land area of 752,618 square kilometers. Hydrologically, the country is divided into six catchments: Zambezi, Kafue, Chambeshi, Luangwa, and Tanganyika. The mean annual precipitation ranges from 1400 mm in the north to 700 mm in the south, with an average surface runoff of 135 mm. In 2020 Zambia's total renewable water resources per capita was 5700.6 cubic meters per year, making it one of the world's water-surplus countries.

Though not a humid country, Zambia has experienced an increased frequency of extreme weather events because of climate change. Incidences of drought, seasonal floods and flush floods, and dry spells along with their intensity and magnitude during the last 45-year period from 1975 to 2017 have increased. Six flood events between 1972 and 2016 caused significant economic damage to agriculture and public and private infrastructure.

Surface drainage or open drains are the predominant type of drainage system in the country and take the form of simple ditches located at the end of the fields. They collect water from the fields at a relatively gentle slope and drain into main drainage channels. These channels are also referred to as storm drains. They are designed with the capacity to cope with runoff resulting from a heavy downpour.

The channels ultimately dispose off the water to the aquatic environment. Pipes are used to connect the drainage ditches at crossing points, such as main and farm access roads. Three types of pipes were found to be in use; concrete culvert rings, asbestos and steel pipes. The sizes vary according to the size of the drainage canal. The excavation of the drainage ditches is usually done by the excavators, Tractor drawn scrappers and planes.This paper highlights the status of drainage in the Southern part of Zambia, with case studies from Mazabuka and Chikankata districts. The paper mainly focuses on the type of drainage systems employed, the drainage infrastructure, as well as the performance of the systems. The author undertook physical visits to selected irrigation farms within the study area to assess the type of drainage systems employed.

Keywords : Drainage, Irrigation Drainage, Drainage ditches, Zambia.

INTRODUCTION

Zambia is a landlocked country located in Southern Africa (Figure 1) and surrounded by eight (8) countries namely, the Democratic Republic of Congo (DRC) in the north, Tanzania in the northeast, Malawi and Mozambique in the east, Zimbabwe and Botswana in the south, Namibia in the southwest and Angola in the west. The country covers a total area of 752,618 km^2 (Holden 2001).

Zambia is drained by two major river systems (Figure 2); the Zambezi and the Congo River basins. The Zambezi basin covers a larger portion of the country and is fed by three rivers; the upper Zambezi, Kafue, and Luangwa Rivers. The Luapula and the Chambeshi Rivers feed the Congo River in the north. The Tanganyika drainage system forms part of the Congo River Basin (FAO, 2005). Zambia is divided into three main agroecological regions (AERs), based on soil type, temperature, and rainfall (Figure 3).

For this paper, the focus will be centred on rainfall. Region I are areas that receives less than 800 mm of rain annually, while regions IIa and IIb fall between 800 to 1,000 mm per annum, and Region III receives 1,000 to 1,500 mm of rain per annum (Makondo et al., 2014).

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Figure 1: Location Map of Zambia (**Source:** Country Report, 2023)

Zambia is endowed with abundant water resources and generates an estimated 104.8 km^3 of surface water and over 47 km^3 of renewable groundwater annually. The total renewable water resources per capita is estimated at 5700.6 m^3 and is considered among few Sub-Saharan African countries that are water secure (Knoema 2020). Zambia has an irrigation potential of about 2.75 million ha of which 523 000 ha are economically viable yet only less than 200,000 ha is irrigated in Zambia (GRZ, 2013). The irrigation potential and the abundant water resource base imply that Zambia, like several other Sub-Sahara African countries, has a huge potential to expand Irrigation (Xie et al., 2014).

The effects of climate change on agriculture directly impact agricultural production and productivity through heightened occurrences of extreme climatic events, especially droughts and floods (Ngoma et al., 2021). Zambia has recorded an increase in the intensity and magnitude during the last 45-year period (NAPA, 2007). Zambia Meteorological Department (2013) rainfall data between 1972 and 2017, show that there have been fifteen (15) droughts during this period (1972/73; 1978/79; 1979/80; 1981/82; 1982/83; 1983/84; 1986/87; 1989/90; 1990/91; 1991/92; 1994/95; 2004/05; 2013/14; 2014/15; 2015/16). Although not as frequent as droughts, records show that there have been six serious flood events between 1972 and 2016. (1977/8; 1988/9; 1999/2000; 2005/06; 2007/8; 2013/14). The floods caused significant economic damage to public and private infrastructure.

Studies by Thurlow et al. (2009) indicate that between 1980 and 2007, drought and flood events were higher than the historical normal. Considering challenges related to climate variability and climate change, irrigated agriculture is seen as a major intervention to mitigate the effects of climate variability based on its contribution to increased production and reduced rate of crop failure (Hoff et al., 2010). Currently, as much as 35 to 40% of the overall agricultural production is realised from just 22% (about 299Mha) of the arable land worldwide that is irrigated (Schultz et al., 2005). Despite the importance of drainage in irrigation, less than a quarter of these irrigated areas are drained (Schultz et al., 2007). This has resulted in problems of salinity and waterlogging affecting ten to sixteen percent of the irrigated arable and permanently cropped areas worldwide.

This has significantly affected agricultural productivity (Ritzema, 2016). The purpose of this paper is to assess the type of drainage systems, type of pipe materials used, and machinery used in the construction of the drainage works in the Mazabuka and Chikankata districts of the Southern Province of Zambia. The information will be submitted to the International Commission on Irrigation and Drainage (ICID) Working Group on Land Drainage (WG-LDRG) for the International Workshop on the State of Drainage Worldwide during the 25th ICID Congress and 74th International Executive Council meeting, scheduled to be held at Vizag, Andhra Pradesh, India from 1-8 November 2023.

Figure 1: Zambia's River Systems (***Source:*** *Hamudud et al., 2017)*

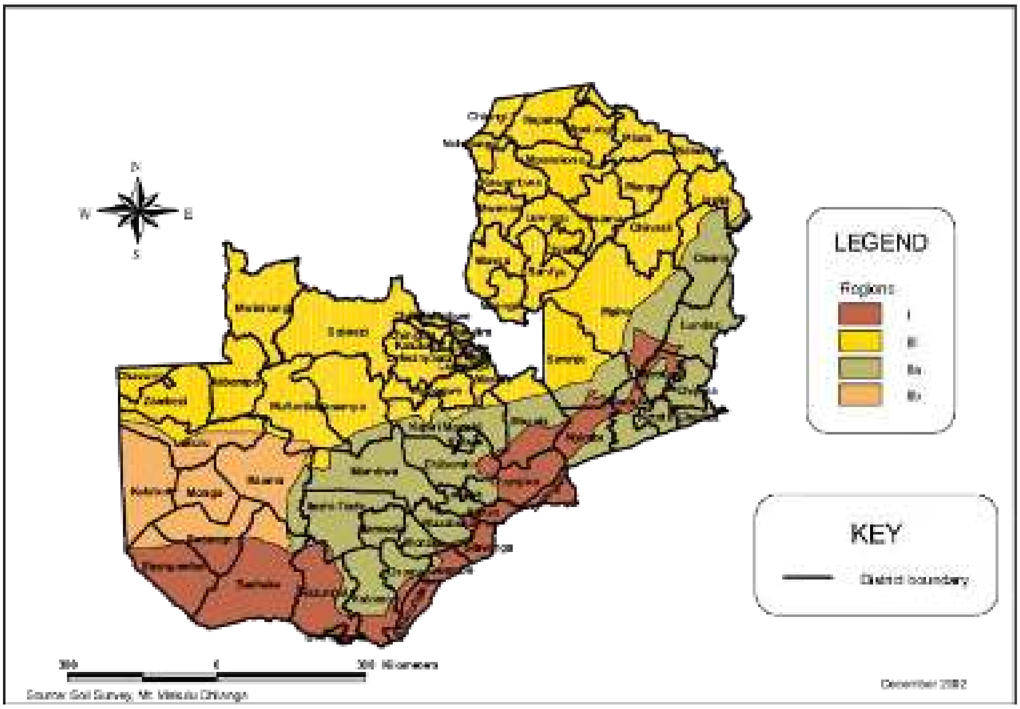

Figure 3: Agro-ecological Regions of Zambia (**Source**: Stephen Haggblade & Gelson Tembo, 2003)

2.0 METHODOLOGY

2.1 Desk Review

The desk review included a review of available information on drainage and irrigation and other relevant information on Zambia's physical, hydrology, and climate.

2.2 Case Study: Mazabuka and Chikankata

Mazabuka and Chikankata districts are in the Southern Province of Zambia, 127 km from the capital Lusaka. Chikankata district was once part of Mazabuka until December 2011 when it was established as a district. The two districts fall under the agroecological region IIa. They account for over 40,000 ha under irrigation and sugar cane is the major irrigated crop in the two districts. The other crops include wheat and bananas. The methodology employed in assessing the drainage systems in these areas was undertaken by visitation to selected farms within the study area. The assessment involved inspection of the drainage system used in the respective farms and conducted structured interviews with key personnel.

2.2.1 Type of Drainage System

Ritzema (2009) describes drainage as key to the success of irrigated agriculture as it plays a key role in developing and maintaining a favourable root zone, having a balance of moisture, air, and salts, for plant growth and development. He further defines drainage as the process of removing excess water from the surface and/or lowering the water table including the removal of salts from the soil.

Two types of drainage systems are referred in irrigated agriculture, and these are surface drainage in which excess water from the surface of the fields is removed by means of naturally enhanced or erected drains. The other is one where excess water and dissolved salts are removed from the subsoil by means of constructed subdrains with the aim of lowering the water table and thus controlling root zone salinity (Ritzema 2009).

2.2.3 Structural Elements of the Drainage Systems

The drainage system is composed of one or a combination of the following essential structural elements: channels, bridges and aqueducts, culverts and siphons, weirs and drop structures, sluice gates, and pumping stations (FAO, 2007). Assessment of the structural elements of the drainage system formed the second part of the assignment on the drainage status. In this part the focus was on the structurual composition of elements making the drainage system.

2.2.4 Equipment/Machinery Used in Drainage Works

The information on the equipment/machinery used in the construction of the drainage ditches is based on the responses from the respondent. In this regard, the equipment/machinery used include Tractor mounted graders, Tractor drawn land planes, GPS-guided cut and fill scrapper, and Excavator.

3. RESULTS AND DISCUSSIONS

3.1 Type of Drainage Systems

The type of drainage system in all the farms visited is **surface drainage** with dominant open waterways or channels taking the shape of trapezoids. One common feature in the layout of the systems is the field drains conveying outflow from the fields to the collection drains that feed into the storm or outlet drain. Before water is discharged into the aquatic environment, it is required that it meets the required water quality standards as regulated by the Zambia Environmental Management Agency (ZEMA), the institution mandated to regulate all environmental issues. This involves regular sampling and testing, usually on a monthly basis. The procedure is a deliberate requirement to ensure the discharge falls within the required water quality threshold to avert pollution of the aquatic environment.

This following sub sections outlines the key findings in the farms visited:

3.1.1 Chilala Farms Limited

The farm has a total area of 650 ha under sugar production. The farm is under centre pivot. The drainage type is surface drainage as shown in figure 4. However, the farm faces a huge drainage challenge mostly during the rainy season. Close to 400 ha (mostly cropped) becomes partially or completely inundated. This is as a consequency of environmental impediment. Figure 5 is a google map showing 3 centre pivots installed along the water course. The circle movement of the CPs wheels crosses the stream at well constructed crossing points. These points partially blocks the stream flow. The result is the flooding being experienced at the farm. This results in poor yields in the affected fields as shown in Figure 6.

Figure 2: River forming part of the drainage system

Figure 3: Google image showing the Infringement of the Stream

Figure 4: Poor crop stand affected by flooding (***Source:*** *Google Earth Images and Author)*

3.1.2 Green Land Farm

the farm is a banana plantation of 38 ha, under micro jet sprinkler system. The drainage in place is surface drainage and takes a simple channel as shown in Figure 7. The performance of the drainage system was reported to be very effective coupled with ideal terrain.

Figure 5: Drainage open channel in a Banana field

3.1.3 Kaleya Small Holder Company

The company manages a gross of 2500 ha of land under sugar cane production. A total of 1075 ha is for the 160 smallholder farmers who own at least 6.5 ha each of farm plots and the remainder 1425 ha is under the company management. The farm has three types of irrigation systems: Surface irrigation system accounting for 2000 ha (80%), centre pivot at 350 ha (14%), and drip irrigation has 150 ha (6%). The farm has plans to extend the area under drip to 300 ha by the end of 2023.

The farm drainage system is surface. The features include an open channel called the main or storm drain that receives water from the collector drains aligned at the periphery of the fields (Figures 9, 10, and 12). The collector drain collects excess water from the field drains. The main drainage channel has the capacity to withstand heavy storm waters.

Figure 6: Microject sprinkler irrigation System (***Source:*** *Author)*

A key feature to note is the reuse of drainage waters. One drainage channel discharge into a storage reservoir from which it is pumped to centre pivots (see Figure 14). The other drainage channel discharges its water directly into the nearby stream. The farm intends to trap this water too for reuse in their expansion programme of the area under irrigation.

Figure 7: Main drain Collecting Water from Collecting Drains

Figure 8: Drainage Canal Delivering Water to the Reservoir

Figure 9: Reuse WAter Reservior Storage

Figure 10: Open Drainage Canal

Figure 11: Water Reuse Pump Station

Figure 12: Centre Pivot Supplied with Reuse Water

Source: Author

3.1.4 Delta Farms

the farm has a total area under irrigation of 3000 ha and the irrigation system employed is centre pivots. The farm is well levelled to facilitate smooth flow of water from the fields to the drainage channel.

3.1.5 Zambia Sugar Company

the company has an excess of 14000 ha under sugarcane production. Figure 16 shows the storm drain with running water. The farm runs a water harvesting system from some outlet drains. This water is reused on the fields laying downstream the retention structure. Figure 17 shows the retaining structure with a sluice gate that regulates the water discharge to the fields downstream. The discharge of water to the aquatic system is regulated by the country's environmental agency, Zambia Environmental Management Agency (ZEMA). In compliance with this regulation, Zambia Sugar has designated four (4) sampling points. The sampling and testing are done once every month. Figure 18 is one of the sampling points.

Figure 13: Delta Farms under Sugar cane Production (***Source**: Author)*

Figure 14: Storm Drain

Figure 15: Sluice Gate Regulating Drainage Water reuse

Figure 16: Drainage Outlet and Sampling Point (***Source***: *Author)*

3.1.6 Mubuyu Farms

The total command area under the centre pivots is 1300 ha. The drainage system was designed by Trevor Beaumont, a consultant. All the information pertaining to the drainage works at the farm is courtesy of Trevor Beaumont. The farm's irrigation system is ubder Centre Pivots (CP).

The irrigation facility has 8 Check Weirs, 7 dams (18 ha of water), Main Mubuyu Dam, (88 ha of water) 17 million m^3. The collector drains also serve as storm drains protecting lower fields from flooding. Figure 19 gives a pictorial view of the farm layout. The storm drain is shown in Figure 20. Reclamation of land under CP 5, 6, 7, and 8 under black cotton soils necessitated water harvesting and pumping into the Main Dam. Drainage from the main road continued to create problems with a large drain through the middle of CP2 leading to the construction of a new drainage channel starting from the road as shown in Figure 21. Despite all these drainage developments, the farm faces drainage challenges in some parcels of land that have prompted the consultant to devise future plans of installing a subsurface drainage system using mole drains and collector drains. The most affected area is CP7 with black cotton soils.

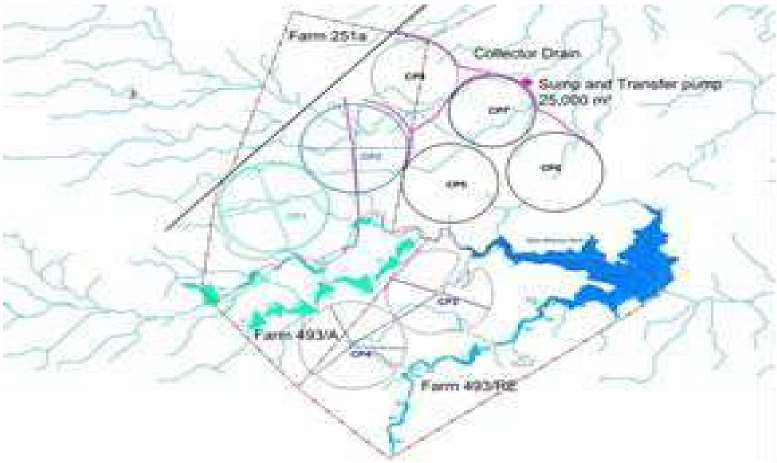

Figure 17: Mukuyu Farm Layout

Figure 18: Storm Drain

Figure 19: Construction of a Drainage Channel (***Source:*** *Trevor Beaumont)*

3.1.7 Lusitu Farms

The farm covers 18 ha under banana production. The source of water is the Lusitu Stream. The fields are on the naturally sloping ground from west to east aiding the smooth flow of water. However, storm drains take up the periphery of the farm to collect storm water during high precipitation events.

Figure 20: Lusitu Banana Plantation

Figure 21: Storm drains at Lusitu Banana Scheme

Figure 22: Lusitu Intake point (***Source:*** *Author)*

3.2 Pipe Materials for the Drainage Systems

The assessment revealed three common pipe types in the drainage system within the study area. The material types include steel, asbestos, and concrete. The figures below show the types of pipe materials.

Figure 23: Asbestos Pipe Aqueducts

Figure 24: Steel pipe Aqueduct

Figure 25: Concrete Pipe Culvert

Figure 26: Asbestos Pipe (***Source:*** *Author)*

3.3 Equipment/Machinery Used in the Construction of Drainage Works

The machinery/equipment used in the construction of drainage include an excavator, GPS-guided cut and fill scrapper, and tractor-drawn land plane. This information is based on the information provided during the study.

Below are the pictures of some of the Equipment/machinery used in the construction of the drainage systems.

Figure 27: Tractor Drawn Plane Levelling the Field

Figure 28: Tractor Drawn Homemade Plane (***Source:*** *Trevor Beaumont)*

Figure 29: GPS guided cut fill scrapper

Figure 30: Construction of drainage Channel (***Source;*** *Trevor Beaumont)*

4. CONCLUSION

The purpose of the study was to assess the type of drainage systems, and materials associated with the drainage pipes and machinery used in the construction of the drainage works in the irrigation facilities in Mazabuka and Chikankata districts of Southern Province of Zambia. Based on the findings of the study it can be concluded that the dominant drainage system in the study area is the surface drainage system that takes the form of open channels shaped in a trapezoidal form. Channels are linked with pipes at the crossing points of farm access and main roads. The material type of pipes in use is of three types: concrete rings, asbestos pipes and steel pipes. The overall performance of the drainage system can be described as effective taking into account their ability to cope with peak runoff. This is attributable to their design capacity. However, drainage challenges are reported in some farms experiencing persistent waterlogging and ponding. Solution to this challenge lies in the use of subsurface drainage system. Future studies on the drainage status of the country is recommended.

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Google Earth Map Chilala farm location 15˚ 48' 29''S 27˚ 57' 46'' E

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POTENTIAL OF PADDY FIELD DAMS IN THE DRAINAGE SYSTEMS OF PADDY FIELD AREAS IN JAPAN

Naoko Koshiyama[1] and Natsuki Yoshikawa[2]

ABSTRACT

Agricultural land, irrigation, and drainage facilities in Japan have been recognized as social capital consisting of personal and public assets, as they provide multiple benefits associated with rice production. Therefore, agricultural water management systems have been developed based on planning standards established by the Ministry of Agriculture, Forestry, and Fisheries, separately from river improvement projects. However, to cope with the frequent flood damages that have occurred in recent years due to climatic change, flood control measures focusing on river improvement have shifted to “watershed flood control measures” for the entire region. One such measure, “the paddy field dam” (PFD), a flood control measure that uses paddy fields, has been attracting attention. A PFD is designed to regulate the amount of rainwater runoff from paddy fields during heavy rainfall by installing devices that reduce the size of the orifice at each surface drainage outlet of the paddy field. Widespread implementation of PFDs can retard rainwater runoff from paddy fields and reduce the peak flow in rivers. With the aim of elucidating the usefulness of the PFD, studies have examine the its effectiveness in reducing inundation water volume using an inundation analysis model and the associated its economic value. The results of the analyses and experiences in various case study areas indicate that the keys to ensuring the effectiveness of PFD are “the implementation of a device that does not restrict the farmers,” freedom of water management,” and “an administrative system that encourages farmers to adopt PFD,” which are necessary to acknowledge farmers’ continuous efforts. This paper outlines the drainage standards for paddy fields in Japan, information on PFD, and the potential of PFD to serve as part of watershed flood control measures.

Keywords: Paddy field dam; Runoff control device; Flood damage mitigation; Drainage Systems; Planning standards for drainage; Japan

1. INTRODUCTION

In Japan, which is located in the Asian monsoon zone, paddy fields provide multifaceted benefits, such as flood mitigation and groundwater recharge, in addition to their primary purpose of rice production. Therefore, paddy fields and their irrigation facilities are recognized as social capital with mixed qualities of private assets and public goods. Therefore, agricultural water management systems and farmland consolidation have been developed separately from river improvement projects, besed on the planning standards established by the Ministry of Agriculture, Forestry, and Fisheries. However, to cope with flood damages that had been more frequent in recent years due to climatic change, flood control measures focusing on river improvement have shifted to “watershed flood control measures” for the entire region.

One such measure, “the paddy field dam’ (PFD), a flood control measure that uses paddy fields, has been attracting attention. A PFD is designed to regulate the amount of rainwater runoff from paddy fields during heavy rainfall by installing devices that reduce the size of the orifice at each surface drainage outlet of the paddy field. Widespread implementation of PFDs can retard rainwater runoff from paddy fields and reduce the peak flow in rivers. With the aim of elucidating the usefulness of the PFD, studies have examined its effectiveness in reducing inundation water volume using an inundation analysis model and the associated economic value. The results of the analysis and experience in various case study areas indicate that the keys to ensuring the effectiveness of PFD are “the implementation of a device that does not restrict the farmers’ freedom of water management” and “an administrative system that encourages farmers to adopt PFD,” which are necessary to acknowledge farmers’ continuous efforts.

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This paper outlines the drainage standards for paddy fields in Japan, information on PFD, and the potential of PFD to serve as part of watershed flood control measures.

2. DEVELOPMENT OF PADDY FIELD DRAINAGE

2.1 History of paddy field drainage development

Japan's agricultural policies changed dramatically during and after the 1950s. Paddy field drainage systems also changed with changes in agricultural policies (Ogino *et al.*, 2007). This section roughly outlines the changes in Japan's agricultural policies and drainage systems.

The Land Readjustment Act was enacted in 1899 to improve arable land through land reclamation and irrigation installations. The initial projects for developing irrigation and drainage canals for agricultural use were agricultural land improvement projects conducted by local governments in 1923. Drainage facility projects are typically conducted in conjunction with reclamation projects. The Land Improvement Act was enacted in 1942 to provide a system for conducting projects operated by the government, prefectures, and other organizations.

Japan achieved rice self-sufficiency by the mid-1950s. Under the Basic Act on Agriculture and Rural Areas enacted in the 1960s, land improvement projects were considered national land consolidation projects whose purpose was to improve the nation's agricultural productivity and increase gross agricultural production. Around 1970, the Japanese government launched "rice production adjustment" and established projects to eliminate the excess supply of rice and increase food self-sufficiency. The full-scale development of under drainage systems has been introduced nationwide to prevent flood damage to fields and promote the cultivation of diverse crops in paddy fields.

With the progress of urbanization in rural areas, drainage projects have gradually shifted from agricultural drainage to area-wide drainage. In addition to preventing flood damage to crops, farmlands, and agricultural facilities, key drainage facilities have been improved to protect the lives and property of local residents. In the 1990s, a project was established to promote beautiful and comfortable rural spaces that incorporated environmental improvements into the development of agricultural drainage channels. Large-scale farming was also promoted during this period, and subsurface irrigation was used to supply water to post-seeding fields under direct seeding cultivation and to crops of rotational cultivation in large plots. A groundwater level control system was introduced in the large plots.

The Land Improvement Act was revised in the early 2000s, and "consideration for harmony with the environment" was clarified as a principle for land improvement projects. Some areas employed simple fish paths between drainage channels and paddy fields to compensate for the height difference between fields and water channels and facilitate fish movement between the fields and channels.

In recent years, owing to climate change, the frequency of heavy rains has increased, and there is concern about an increase in natural disasters, such as flood damage, in rural areas. Thus, the importance of drainage facilities has increased. Primary agricultural facilities developed from the postwar period to the high economic growth period have been aging, and there are fears that they could lose their functionality at any time. Therefore, efforts are being made to improve rural areas' disaster prevention and mitigation capabilities, restore facility functionality, and extend their service lives.

2.2 Planning standards for drainage

The Ministry of Agriculture, Forestry, and Fisheries of Japan (MAFF) stipulates planning and design standards for land improvement projects. Land-improvement planning and design standards consist of standards and technical documents. The standards document includes essential/normative matters, specific provisions, and explanations for each topic, whereas the technical book includes general technical explanations, standard plan examples, and other reference information. In 1954, the Ministry of Agriculture and Forestry enacted planning standards for drainage, and revised them several times. The MAFF revised the Planning Standards Book in 2019 and Technical Book in 2020.

The planning standards cover project plans for primary drainage facilities that control the drainage conditions of fields. However, in principle, they do not cover external conditions in areas with drainage facilities. In other words, these standards do not cover the flood control plan of the catchment basin. Field facilities for surface drainage are explained in the section titled “Farmland consolidation (paddy fields),” “Farmland consolidation (upland crop fields),” and those for underdrainage in fields are in the section titled “Subsurface drainage.”

3. THE ROLE OF PADDY FIELDS IN WATERSHED FLOOD CONTROL

The concept of “green infrastructure” has gained attention as a measure to alleviate the impact of climate change. The use of nature’s functions and mechanisms in disaster prevention and mitigation has become widely recognized, both domestically and internationally. Regular rice farming practices, including the puddling of fields and filling of field ridges, unintentionally contribute to flood control by conferring flood mitigation capabilities to paddy fields. Therefore, no cost was incurred in achieving the objective of flood mitigation. In this context, the concept of green infrastructure contrasts with “gray infrastructure,” such as dams and river levees, which require a large amount of maintenance and management costs for maintaining their flood control functions, and the more new facilities we build, the higher the maintenance costs.

In response to the frequent occurrence of large-scale floods in recent years, the Ministry of Land, Infrastructure, Transport, and Tourism changed its policy on disaster prevention and mitigation measures in 2020. The trend has shifted from flood control measures that focus primarily on rivers, such as river improvement and dam construction, to “watershed flood control” in which all stakeholders in the basin are involved in flood control measures. Under these circumstances, efforts by authorities and farmers to utilize paddy fields to enhance their storm water storage capacity, namely, paddy field dams (PFD), have been gaining attention.

4. PFD IMPLEMENTATION

4.1 What are PFDs?

Niigata Prefecture is the birthplace of PFDs, with the first PFD introduced in 2002. PFDs have a straightforward mechanism of action, in which a device is installed to reduce the drainage outlet diameter (Figure 1). For the storage function of paddy fields, Shimura (1982) and Masumoto (1998) evaluated that how the storage of rainwater in paddy fields controlled the runoff into the rivers. With PFDs, the idea is that the installation of a runoff control device reduces runoff from paddy fields in addition to the field’s ability to store rainwater. On a catchment basin scale, it is possible to prevent large amounts of rainwater from concentrating in rivers by allowing rainwater from urban areas, which are prone to runoff at an early stage of rainfall, to flow down into the rivers first and delay runoff from paddy field areas. As of 2022, PFDs will be practiced in over 60,000 ha of paddy fields in Japan.

Runoff Control Device (RCD)

Drainage Outlet

Figure 1. How a PFD works.

4.2 Necessity of visualizing the effectiveness of PFDs

In rural areas with paddy fields, drainage systems have been developed to prepare for rainfall with at least a 10-year probability. Therefore, the PFDs are expected to be effective in controlling floods when heavy rainfall occurs at or above this level. However, when the recurrence period of heavy rainfall in a given area is long, farmers and residents cannot accurately remember the damage they experienced in the most recent event. Even if they remember past damage, it is difficult for farmers and residents to compare current damage with previous damage, because rainfall intensity and duration are different. Therefore, it is difficult for local people to clearly perceive the effectiveness of PFDs.

Furthermore, even if PFDs can reduce flood damage, they do not completely eliminate it; therefore, it is difficult to determine the extent to which this new approach can contribute to damage reduction in affected areas. When introducing this new approach, it is essential to present the significance of PFDs in an easy-to-understand manner, not only to the farmers who participate in this new attempt but also to the downstream beneficiaries who enjoy the benefits of PFD introduction.

Yoshikawa et al. (2011) developed a simulation model to visualize the flood control effects of PFDs. As there is no model that can accurately reproduce the complex runoff/inflow mechanisms of paddy fields (e.g., free runoff, submerged runoff, backflow, and overflow between rice paddies) and evaluate the effects of PFDs on the entire watershed, a new model was developed specifically for this purpose.

4.3 Effectiveness of PFDs in mitigating flood damage

The developed model was used to estimate the flood control effects of PFDs in low-lying agricultural areas. The results showed that PFDs could reduce the flood water volume by approximately 20% to 30% for a rainfall event with a probability of approximately 30 years. However, the reduction rate depends on the paddy field area as a share of the entire watershed area, drainage conditions, and other factors (Figure 2).

In addition, the economic value of the PFDs was estimated based on the calculated flood control of the PFDs. For example, the expected economic value is estimated to be 320 million yen per year in Shirone. Dividing this by the PFD project area of 2,900 ha yields 11,200 yen/10a/year. Compared to the average income from rice cultivation (about 20,000 yen/10a/year), which is the original function of paddy fields, PFDs are expected to bring more than half the income farmers earn from rice cultivation.

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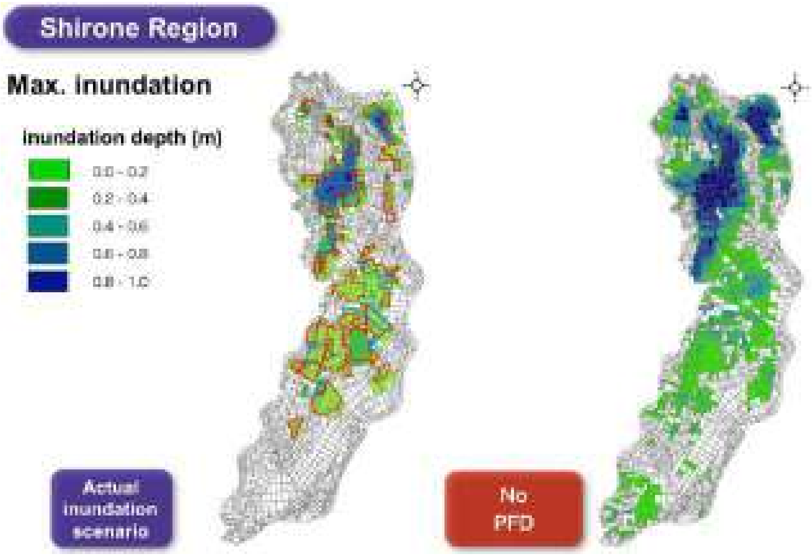

2.

Figure 2. Example of the flood control effectiveness of PFDs

4.4 Factors that hinder continuing efforts to implement PFDs

Appropriate equipment design is essential to ensure that PFDs can continue to be implemented over the long term. Examples of appropriate devices are shown in Figure 3. The crucial point in designing PFDs is to avoid restricting the farmers' freedom of water management during paddy cultivation. Once the equipment is installed, no operation is required for the PFDs, which is essential not only to reduce the management efforts of farmers, but also to ensure the effectiveness of PFDs.

In addition to adopting appropriate devices, the key to supporting sustainable efforts to introduce and disseminate PFDs is an administrative mechanism that facilitates the creation of incentives for farmers. The goals of PFD projects differ significantly from those of conventional flood-control measures. Conventional flood control measures achieve their goals through the construction of facilities. However, PFD projects begin with the installation of devices, and the flood-control effectiveness of PFDs depends on their maintenance by farmers.

However, PFDs are characterized by their ability to control flood damage downstream through the efforts of upstream farmers. Therefore, farmers who bear this burden are often not beneficiaries. Upstream farmers who do not directly benefit from PFD have no reason to actively participate in its implementation. Furthermore, the practice of drawing water from water sources in favor of farmers who have fields upstream of rivers and canals persists. This sense of entitlement among farmers in upstream areas is at odds with the burden-benefit relationship of the PFD concept. This situation was a major factor that prevented consensus building at the time of PFD introduction and undermined the continuity of efforts after its introduction.

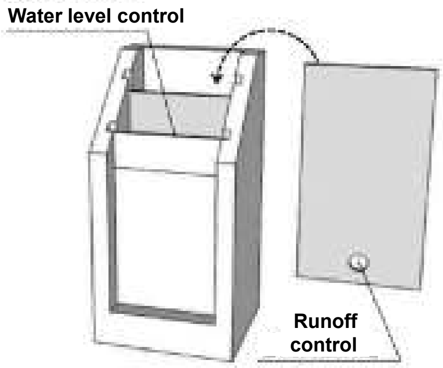

Figure 3. An example of drainage adjustment device

4.5 Necessity of systems that support continuous efforts for PFD implimentation

To correct the problems described in the previous section, there was a strong demand to incentivize farmers. Many of the efforts to introduce PFD rely on the government's multifunctional payment subsidy systems. Subsidies were provided according to the total area of the paddy fields. However, it is difficult to substantially expand efforts to introduce PFDs with only this system because even in districts where PFDs are implemented, there are cases where the devices are removed during heavy rainfall. Furthermore, there are cases where PFDs are not implemented in districts in the upper reaches of the river or canal with a high potential for flood mitigation, but are implemented only in districts at the lower reaches of the river or canal. These are areas where PFD implementation is in name only.

As a helpful example, Mitsuke City, Niigata Prefecture, marks a cutting-edge PFD promotion area. Since 2010, the city has installed PFDs on 1,200 ha of paddy fields. More than 12 years after this project has begun, PFDs remained in use on at least 95% of the 1,200 ha of paddy fields. The most noticeable feature of the Mitsuke City scheme is the establishment of a "regional agreement". Although it is assumed that subsidy-based activities will be carried out on a village-by-village basis, Mitsuke City regards the 65 villages within the city as one activity organization through regional agreement. PFD-related activities eligible for subsidies include levee mowing and filling. Farmers own levees, and levee management is part of individual farming activities. Therefore, levee maintenance was not considered eligible for subsidies.

However, Mitsuke City decided that levees were essential facilities for PFDs, which store rainwater in paddy fields, and that the maintenance of facilities collectively used by the community was essential for maintaining the functionality of PFDs. Based on the city's decisions, an allowance based on the amount of work required to maintain the paddy field levees was paid out of the subsidy. In addition, to ensure the sustainability of the PFD initiative, Mitsuke City pays a “consignment fee” to each farmer in the project area from its financial resources (Figure 4). Each district representative directly hands a letter of appreciation for the farmer’s cooperation in improving safety through flood control, along with the consignment fee from Mitsuke City. Through the activities of city and district representatives, farmers feel responsible for the effectiveness of PFDs. As a result, they actively participate in activities to maintain PFDs. The consignment fee was only 500 yen per device; however, this payment was significant.

By establishing such a scheme, the maintenance activities of the PFD in Mitsuke City motivated farmers to properly and actively manage their paddy fields rather than simply being based on volunteer spirit. Regional agreements have led to activities that extend beyond the boundaries of communities and have mitigated the devastation of agricultural land throughout the region.

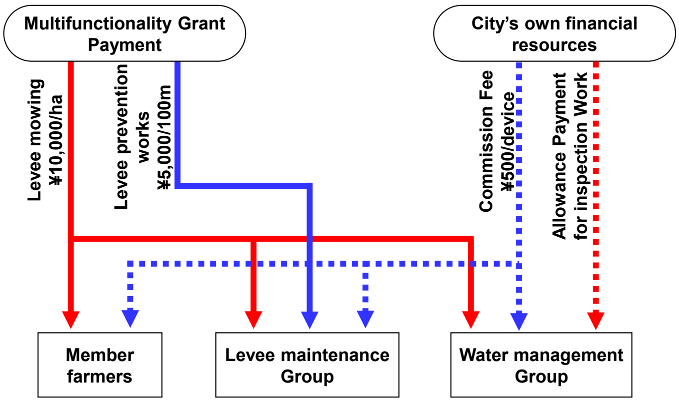

Figure 4. PFD-related activities and payments for such activities

5. POTENTIAL OF PFDs AS A WATERSHED FLOOD CONTROL MEASURE

The Ministry of Agriculture, Forestry, and Fisheries is an administrative agency whose primary purpose is to promote a stable food supply. Flood control is outside its jurisdiction. Although the Ministry of Land, Infrastructure, Transport, and Tourism, which has jurisdiction over flood control, was highly interested in the flood control effects of PFDs, there was almost no active involvement in the introduction of PFDs because it was an effort to use agricultural land that was outside its jurisdiction. However, after the Ministry of Land, Infrastructure, Transport, and Tourism announced a policy change for basin-wide flood control, it became possible for the Ministry of Agriculture, Forestry, and Fisheries to contribute to flood control measures, overcoming barriers between and within the authorities.

Although the momentum for the dissemination of PFD has increased, there has been a flurry of activity toward its dissemination, and many municipalities have attempted to implement PFDs without fully understanding their mechanisms and characteristics. Therefore, the following two points should be carefully considered: The first was to clarify the objective of the effort by identifying the types of damage to be mitigated and their scope. It is necessary to consider in advance the causes of flooding in the area and the extent to which PFDs have been effective in resolving them. The second was to determine whether PFDs have a significant effect on the river basin in which they are being considered for implementation. The effectiveness of PFDs depends on the ratio of the paddy field area to the watershed area. More than 70% of Japan’s land area is mountainous, and paddy fields account for slightly more than 6% of this area. Thus, the larger the target watershed, the greater the share of mountainous areas, and the PFD has limited effectiveness in larger watersheds with limited paddy field areas.

The potential of PFDs to control flooding depends on the watershed topography. In low-lying paddy field areas, backwaters form when the water levels of drainage canals rise, causing phenomena such as the suppression of runoff from paddy fields, backflow from drainage channels into paddy fields, and inflow into paddy fields over ridges. When the drainage channel water level rises, the outflow from the paddy field is suppressed; thus, the PFDs do not work as expected.

Examples of watersheds with steep topographic gradients are as follows: The Tagawa River in the Tochigi Prefecture is a first-class river. Paddy fields accounted for 23% and mountainous areas accounted for 49% of the 166 km2 catchment area. The river is located 34 km upstream of the urban area of Utsunomiya City, the prefectural capital, and has a topographic gradient of 1/150. Of the 166 km2 of the river basin area, 23% is covered by paddy fields and 49% by mountains. First, the validity of the inland flood analysis model was examined by reproducing the current case, in which PFDs were not implemented, using the rainfall of Typhoon Hagibis in 2019 as an external force. Based on this verification, the flood control potential of the PFDs was evaluated using a scenario that assumed that PFD were implemented in all paddy fields in the catchment basin of the Tagawa River. The 24-hour rainfall observed at this time was 414 mm, which is equivalent to a 500-year probability of rainfall, and two-thirds of the rainfall was concentrated in the 6 h that the typhoon passed through the area. The PFDs in the watershed reduced the peak discharge at the overflow point by approximately 200 m3/s, which was equivalent to 9% of the peak discharge at that time. From this result, we found that PFDs have the potential to reduce the inundation area in urban areas by approximately half, the total volume of inundation by one-third, and above-floor inundation by approximately 40% (Figure 6). Thus, when there are many paddy fields on slopes beyond a certain steepness, the paddy fields tend to be relatively free from the influence of backwater. PFDs have demonstrated full potential for flood control in many paddy fields.

As shown in these examples, the flood control effectiveness of PFDs varies depending on the catchment basin topography. Therefore, while recognizing the PFDs as a nationwide watershed flood control measure, it is necessary to first “visualize suitable areas where flood control effectiveness can be expected”.

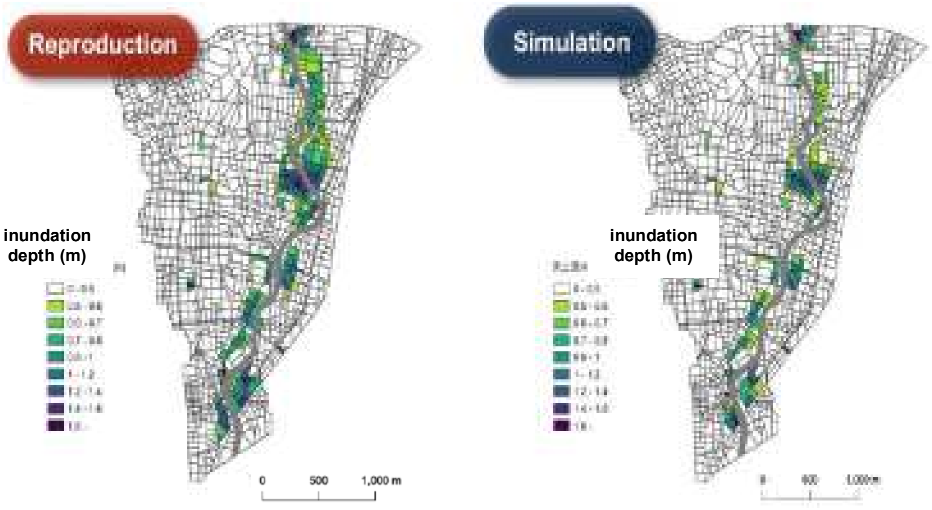

Figure 6. Reduction in the area of above-the-floor inundation

6. CONCLUSION

Japan has extremely low food self-sufficiency. On a calorie basis, it has halved from 74% in 1960 to 37% in 2020. In the 1960s, the types of food consumed by Japanese people began to diversify, and per capita rice consumption continued to decline due to a shift in consumption patterns. In 1970, rice production adjustments began under the government’s policy of reducing paddy field areas. Furthermore, the area of paddy fields has continued to decrease owing to the declining population, decreasing number of farmers, and the aging of farmers. This has increased the number of uncultivated and devastated paddy fields. Such devastation and a reduction in paddy cultivation mean that various benefits have been lost. From the viewpoint of food security, preventing a further reduction in farmland is the nation’s most basic and greatest proposition for protecting the lives of its people. Thus, the PFD promotion policy is a measure for managing agricultural resources. If there is no choice but to reduce the cultivated area owing to the oversupply of rice, there may be a way to preserve paddy fields by managing them as PFDs. Farmers would not plant rice in such fields, but would perform only basic maintenance, such as plowing and ridge filling. This would contribute to catchment basin flood control during normal times and secure an environment in which rice cultivation can be initiated immediately in the event of unforeseen circumstances. We hope that PFDs will play an essential role in supporting food security, in addition to their role in conserving national land by mitigating flood damage.

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SUB-SURFACE DRAINAGE UNDER THE LINING OF ODERO LAL BRANCH CANAL IN SINDH PROVINCE OF PAKISTAN

Fazal Rehman Kashif[1], Haji Khan Jamali[2], M. Ahsan Latif[3]

ABSTRACT

This paper highlights the importance of adopting an integrated approach that incorporates drainage considerations into the planning and execution of water resource development initiatives. Such an approach is indispensable for ensuring project sustainability and optimizing outcomes. The study focuses on a project in district Thatta of Sindh province wherein Oderolal Branch (OLB) canal has been subjected to concrete lining along with provision of sub-surface drainage. It was initiated when the need for water conservation was perceived. Therefore, it was aimed to store surplus/flood water in Kharif Season by reduction of conveyance losses of Kalri Baghar Feeder Lower (KBFL) system and extension of existing lakes.

OLB, the branch canal of KBFL system follows as deep-cut sections at certain reaches and partially cut/fill section in some reaches. A drainage system exists in the study area though, it is not sufficient for canal relief which even experiences impact of water of several fish ponds adjacent to canal. So, lining of canal to reduce conveyance losses was not a sole objective, rather safety of lined canal from surrounding high groundwater acquired more attention. Analysis of collected data of groundwater levels in surrounding of OLB endorsed the same fact and urged to propose feasible intervention. Therefore, subsurface drainage system was proposed underneath lining for about 101,000 ft length in different reaches.

Seepage analysis program SEEP/W has been used as well to evaluate the groundwater profile in the post-lining scenario. Various scenarios developed by placing Pressure Relief Valves at various locations to decide the best hydraulic position to get the maximum relief of seepage pressure. The provided drainage arrangements depend mainly upon the position of water table and the type of subgrade. PRVs have been installed within canal bed for one of the reaches for 2,000 ft length. During recent canal closure, these PRVs have behaved properly by reducing the excess pore pressure and have indicated the safety of canal against the worst condition.

INTRODUCTION

The agro-based industrial development is an indisputable fact that carried out a dynamic role for the economic development of Pakistan [1]. Water is the single most important input of Irrigated agriculture which greatly contributes towards increase in crop production [2] .Availability of water supplies is already limited and different ways and means have to be devised to prevent its wastages at all levels [3]. High losses of valuable irrigation water through unlined canals is one of the main reasons of salinity and water logging in culturable lands[4]. It is recommended in such cases to line the canals with best economic type of lining. Main advantages derived from lining a canal are minimizing seepage losses in the canal, increasing conveyance efficiency and reduction in maintenance costs[5]. Most of the lined canals gets cracked due to excessive uplift pressure forces under the lining when the groundwater table rises above the canal bed during periods of low flow or no flow [6]. This study highlights the similar problem of Oderolal Branch (OLB) canal.

OLB lies within the Thatta district of Sindh Province, Pakistan as shown in Figure 1. Total length of OLB is 201,000 ft. It is the part of KBFL distribution system and has served as inundation canal in the past.

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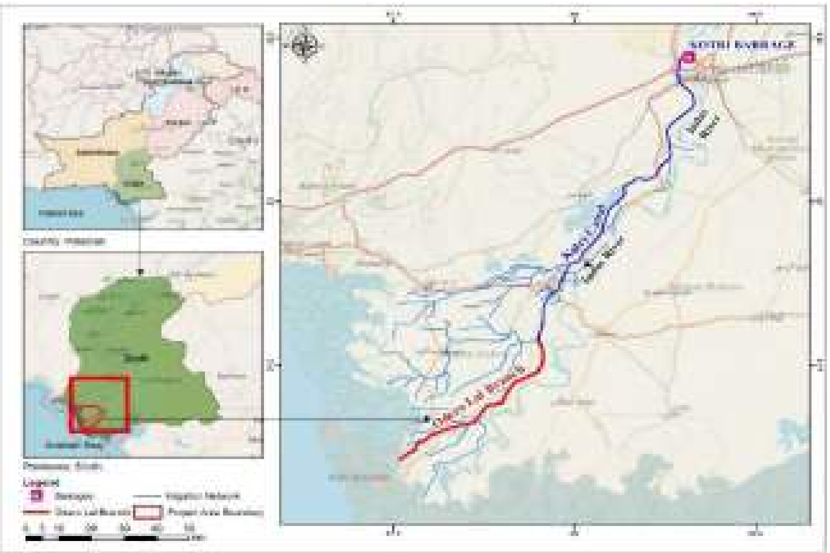


Figure 1: Location Map of Oderolal Branch Canal

PROBLEM STATEMENT

Longitudinal section of OLB follows as deep cut sections at certain reaches and partially cut / fill section in some reaches. Canal lining was proposed to increase the conveyance efficiency of canal with assured supply to tail reaches. Safety of canal lining, however, emerged as significant part of the study due to surrounding high groundwater table. Adjoining fish ponds (as shown in **Figure 2**) parallel to OLB intensifies the impact of elevated ground water table and posed the threat to stability of concrete lining during closure due to developed pore pressure. Hence, necessitated the drainage intervention to prevent the lining against all critical scenarios.

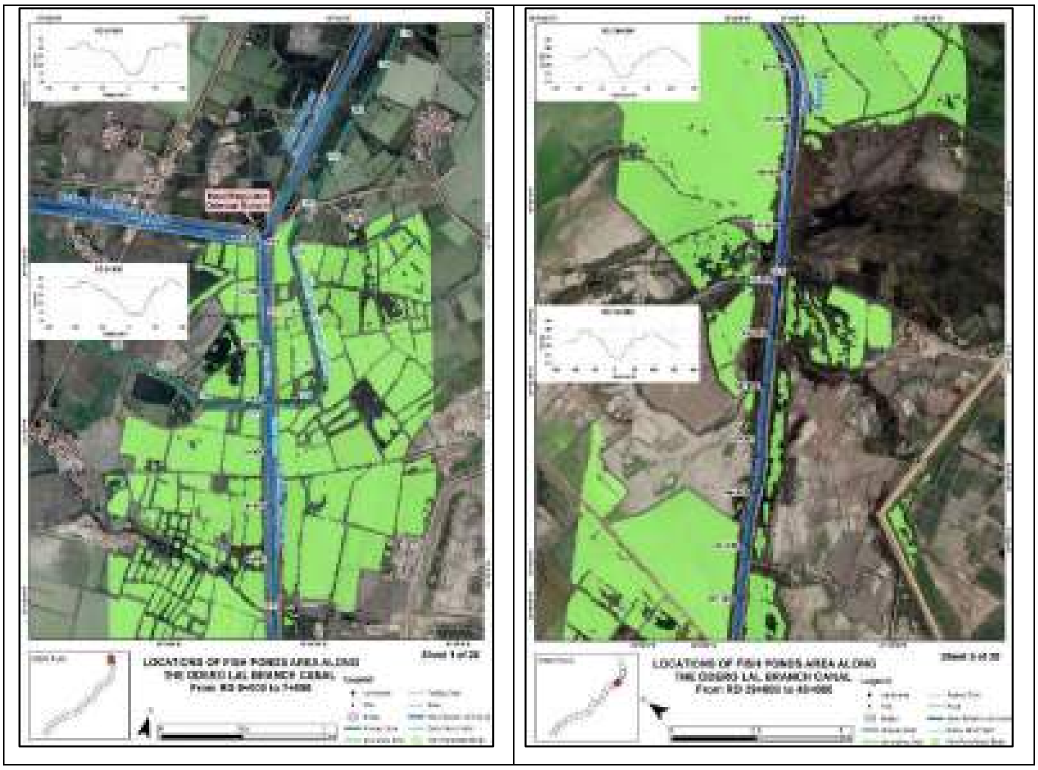


Figure 2: Fish Ponds Parallel to OLB

STUDY OBJECTIVES

The study aims to appraise the necessity of sub-surface drainage under concrete lined canal where groundwater table is too high. Also give prominence to the appropriate position of proposed sub-surface drainage to get the maximum relief of seepage pressure.

APPROACH & METHODOLGY

The project was aimed at saving water and to develop a sustainable roadmap for management of water resources in the study area to store surplus/flood water in Kharif Season. It was necessitated for extension & integration of existing lakes and improvement of Kalri Baghar Feeder Lower (KBFL) system by reduction of conveyance losses to save considerable quantum of water. Accordingly, concrete lining was perceived as most feasible intervention to save water through conveyance system. Hence, safety of lining draws out more attention owing to surrounding high groundwater table.

Following approach and methodology has been adopted to address the aforementioned problem related to OLB. Same is presented in detail in subsequent sections

- Problem Identification
- Proposal for sub-surface drainage under lining
- Seepage analysis of proposed lined OLB in context of Sub-Surface Drainage
- Performance evaluation of concrete lining with sub-surface drainage

Problem Identification

Foreknowing the issue of surrounding high groundwater table, ground water data was collected from 2008 to 2014 and 2019 to study the water logging of Thatta irrigation Zone. The data was processed in ARCGIS to create water table contours for pre and post monsoon, revealing higher groundwater levels in some reaches. Field visits endorsed the extensive waterlogging and unhealthy crops due to poor surface drainage as well. Data was further subjected to the comparison with longitudinal profile of OLB as shown in Figure 3. As per figure, ground water elevations significantly exceeded from bed level from 130+000 RD to 160+000RD. Overall analysis of ground water data reflected the higher water table near by canal. Hence, urged to proposed reasonable feasible intervention

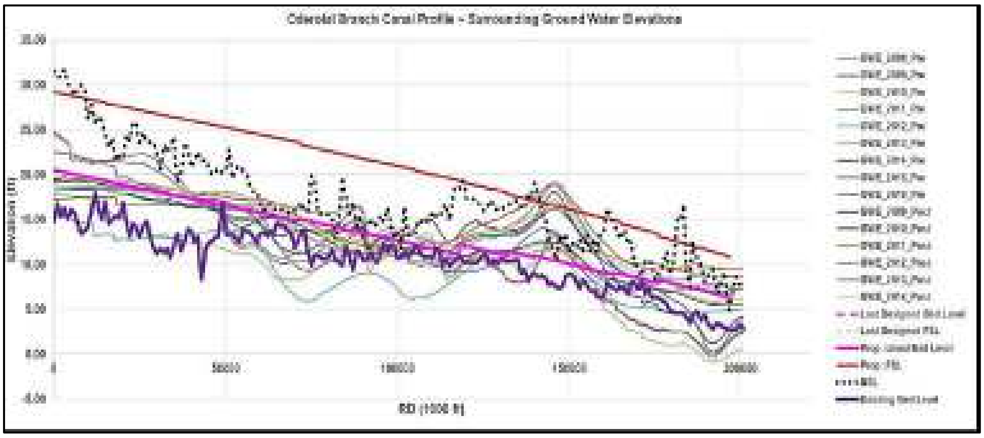


Figure 3: Longitudinal profile of OLB with Pre & Post-Monsoon data of Ground Water Elevations
Proposal for Sub-Surface Drainage Under Lining

Prior to propose any intervention for safety of lining against the uplift pressure due to underlying groundwater, existing drainage network surrounding of OLB was firstly identified as shown in Figure 4. It was exercised in context of feasible intervention for proper disposal of drainage effluent i.e. to identify the canal reaches where intercepted effluent through proposed sub-surface drainage could be disposed off efficiently.

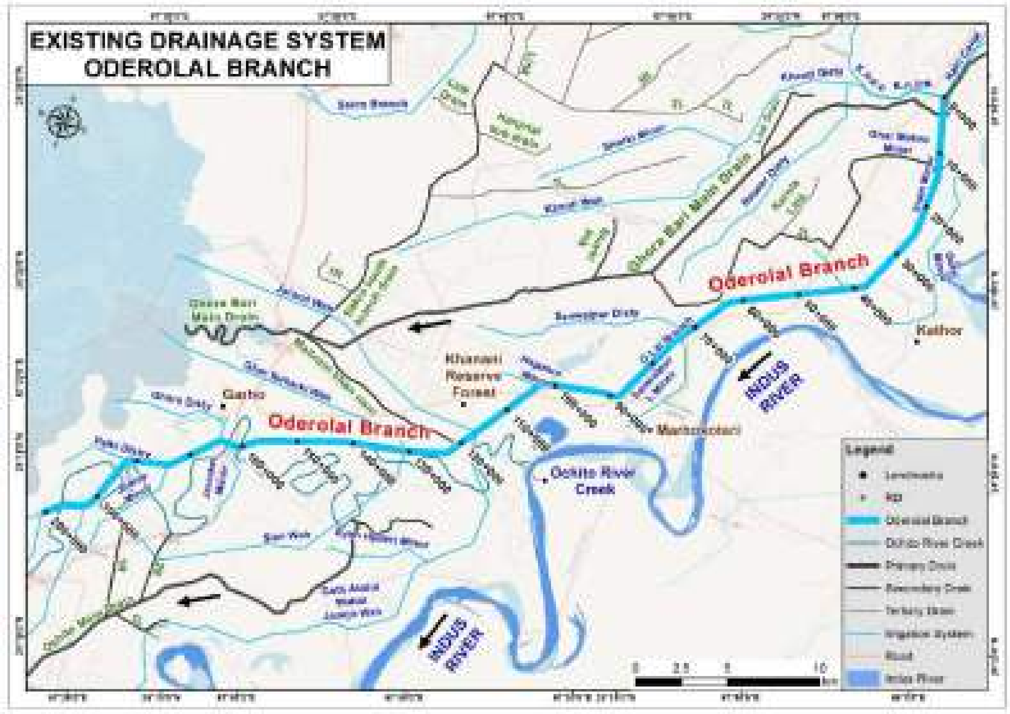


Figure 4: Existing Drainage System in Surrounding of OLB

Accordingly, a sub-surface drainage system has been proposed underneath the canal bed for various reaches. Critical reaches of canal under the influence of high groundwater table were firstly recognized. Corresponding discharges were then calculated. Seepage analysis program SEEP/W has been used to evaluate the groundwater profile in post-lining scenario and to determine drainable surplus to be removed underneath the bed formation for safe uplift pressure under PCC lining. Permeability value of soil strata was adopted as 3.28 x 10^{-5} ft/sec. Analyses have been performed for varying groundwater levels as follows:

(a) Below canal bed level,

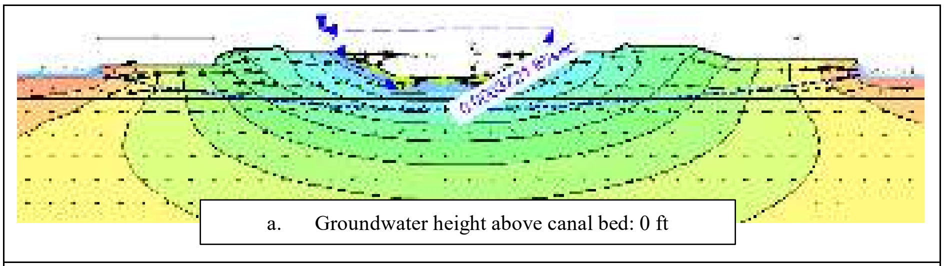
(b) Between canal bed and full supply level, and

(c) Above canal full supply level

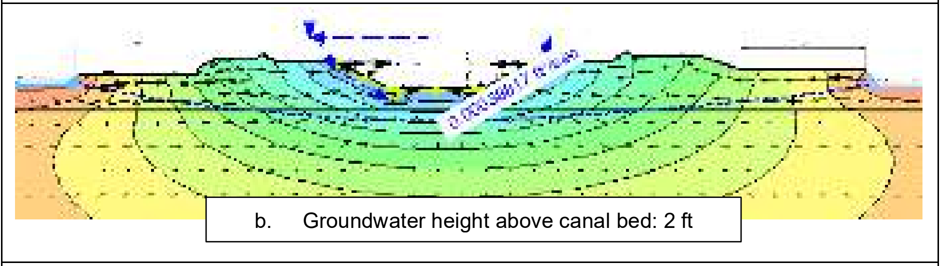
Results of analyses recognized that the higher ground water elevation relative to canal bed pose excessive pore water pressure on canal prism as depicted in **Error! Reference source n ot found.** (a tod). Hence, endorsed the provision of sub-surface arrangement for critical reaces. Calculated drainable discharge corresponding to separated segments is provided in following table;

Table 1: Calculated Drainable Discharges for Sub-Surface Drainage System

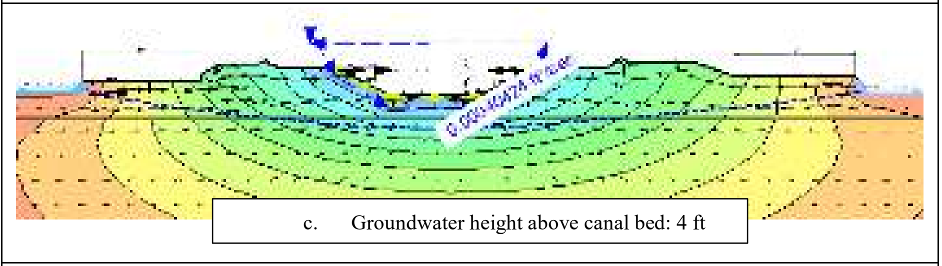
Segment			Drainable Discharge (cusec)
Sr. No.	**From RD**	**To RD**	
1	0+500	8+500	3.6
2	9+500	19+500	4.4
3	20+500	63+000	17.2
4	118+500	136+500	7.4
5	140+500	160+000	8



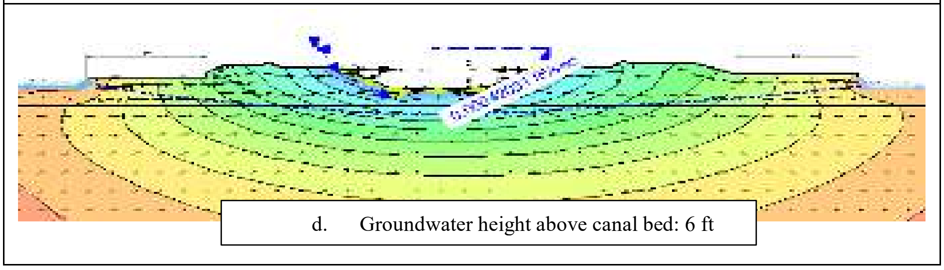
a. Groundwater height above canal bed: 0 ft



b. Groundwater height above canal bed: 2 ft



c. Groundwater height above canal bed: 4 ft



d. Groundwater height above canal bed: 6 ft

Figure 5: Results of Seepage Analysis of OLB for Varying Groundwater Levels

After assessment of drainable discharge, drainage arrangement has been designed such a way that uplift pressure on lining does not increase beyond the safe limit The sub-surface drainage system has been divided into 5 segments which are tabulated extensively in Table 2.

Table 2: Summary of Sub-Surface Drainage System

Segments			**Description**
Sr. No.	**From RD**	**To RD**	
1	0+500	8+500	-RD 0+500 to 3+000 along canal flow direction -RD 8+500 to 3+000 in reverse direction
2	9+500	19+500	-RD 9+500 to 13+000 along canal flow direction -RD 19+500 to 13+000 in reverse direction
3	20+500	63+000	-RD 20+500 to 63+000 along canal flow direction
4	118+500	136+500	-RD 118+500 to 136+500 along canal flow direction
5	140+500	160+000	-RD 140+500 to 160+000 along canal flow direction

Reaches for proposed sub-surface drainage were designated as per convenience to dispose off the collected discharge. Same is represented through Figure 6 and Figure 7, showing Ghora Bari Main Drain and 2L-Drain to accommodate the disposal of proposed sub-surface drainage system.

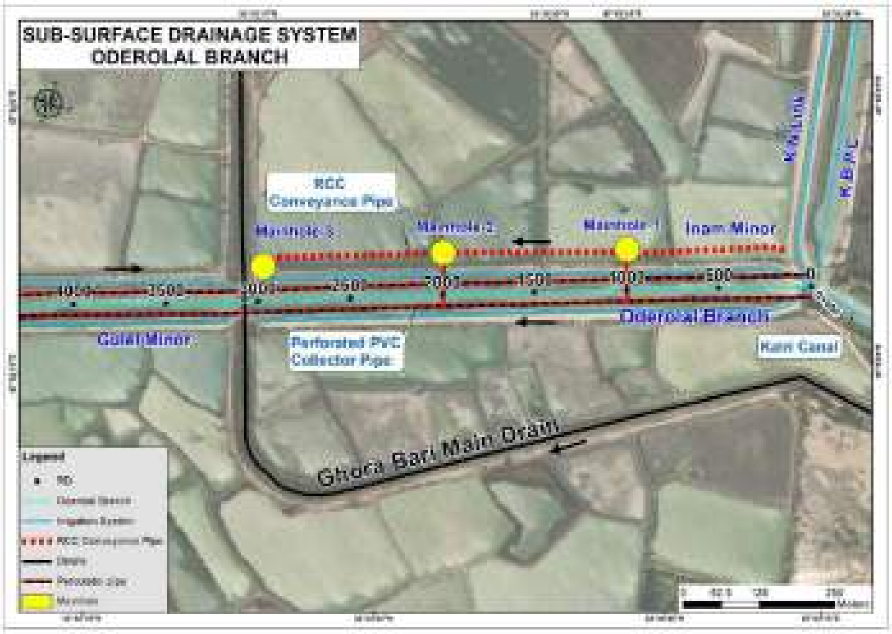


Figure 6: Disposal of Proposed Reach (RD 0+500 to RD 8+500) at RD 3+000

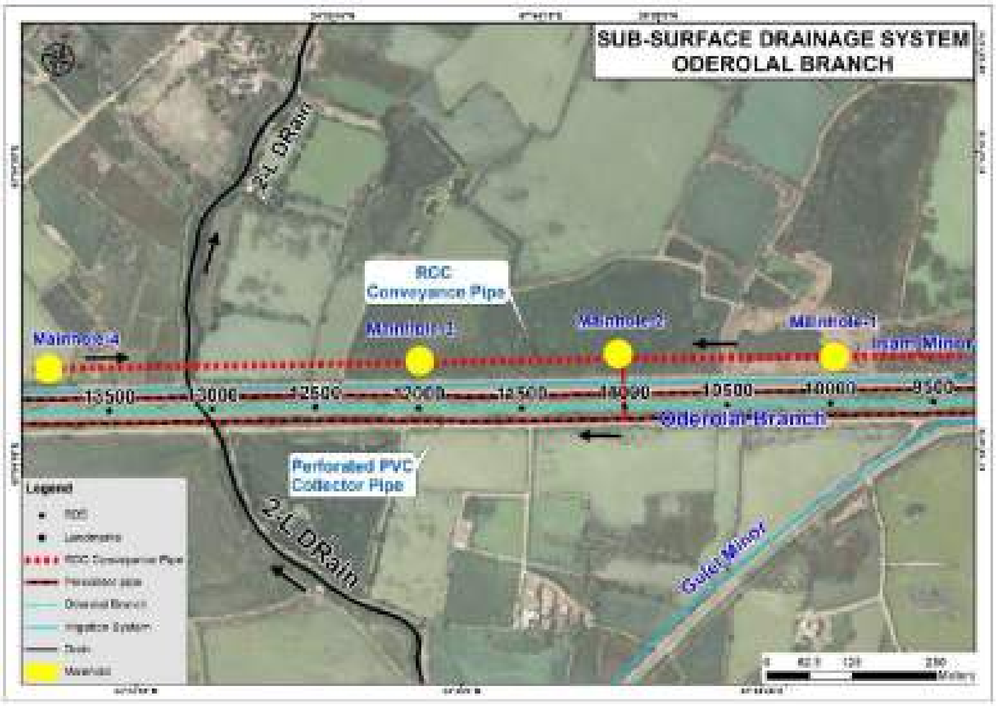


Figure 7: Disposal of Proposed Reach (RD 9+500 to RD 19+500) at RD 13+000

Overall drainage system involves following components, depicted as well through typical plan in Figure 8;

- Network of PVC perforated pipes under canal bed
- RCC collector pipes to convey water from PVC perforated pipes to adjacent Manholes
- Main RCC pipes parallel to canal to convey the water to ultimate disposal point/ surface drain under gravity flow.

- All the pipes underlying canal bed would be PVC perforated whereas others would be RCC.
- Pressure Relieve Valves (PRVs)

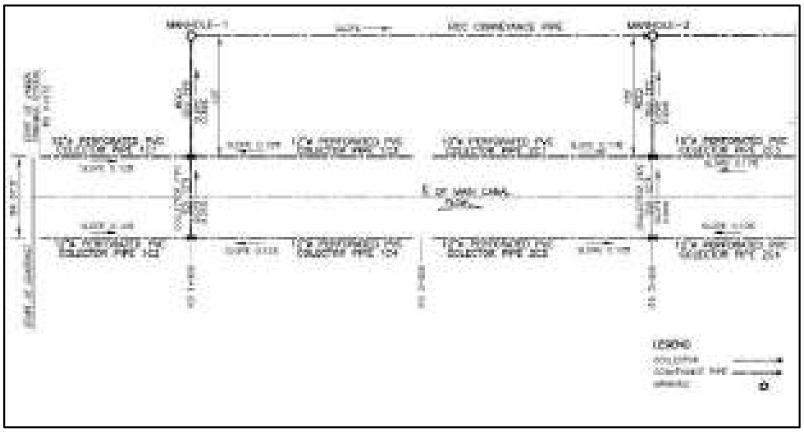


Figure 8: Typical Sketch of Proposed Sub-Surface Drainage

The laterals in transverse direction to the canal flow, abstracts the ground water from the canal bed and transmit it in to two collectors provided in canal bed in the toe of side slopes parallel to the flow. The collector in the right-side toe and the collector in left side toe joins with each other by a transverse pipe. The joint discharge of both collectors is delivered to the manhole through RCC collector pipe. Each manhole adds the water abstracted from every 2000 ft length of Main canal. Main conveyance RCC pipe then receives the discharge through manholes and deliver to ultimate disposal point.

PRVs were further proposed for more critical reaches and suggested to install as per observations on site and pertinent analysis on SEEP/W software for location of their placement.

Seepage Analysis of Proposed Lined OLB in context of Sub-Surface Drainage For significantly critical reaches qualitative comparative analysis was carried for various sub-surface drainage option to analyse their effectiveness. Initially it was perceived that hydrostatic pressure underneath the canal lining firstly effects the canal bed so, PRVs were proposed at the centre of the canal bed. From results it was observed that the hydrostatic pressure was still high near the edges and side slope of canal as shown in **Figure 9**. Then PRVs were proposed near the edges of canal bed, resulted the effective release of hydrostatic pressure near edges and also diffusing the impact over entire canal bed as shown in **Figure 10**. Further, PRVs were proposed over the side slope of the canal bed in addition to PRVs near edges of canal bed shown in **Figure 11**. Results showed that hydrostatic pressure was decrease a bit more than second scenario but not significantly, hinting the burden over project cost. Hence, compiled results showed that provision of PRVs near the canal edges resulted as most optimal orientation for PRVs. So, it was proposed to provide PRVs only near the edge of canal bed on both side as shown in **Figure 12**.

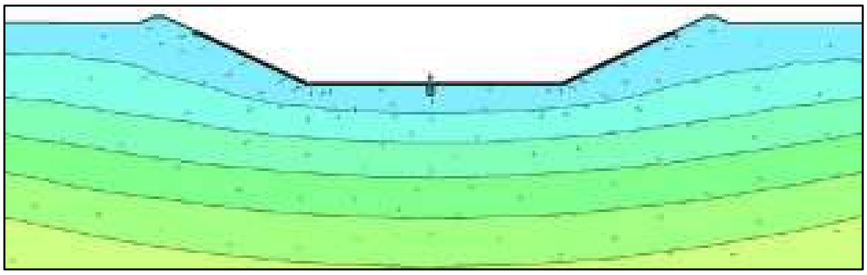


Figure 9. Results of SEEP/W with provision of PRVs at mid of canal bed

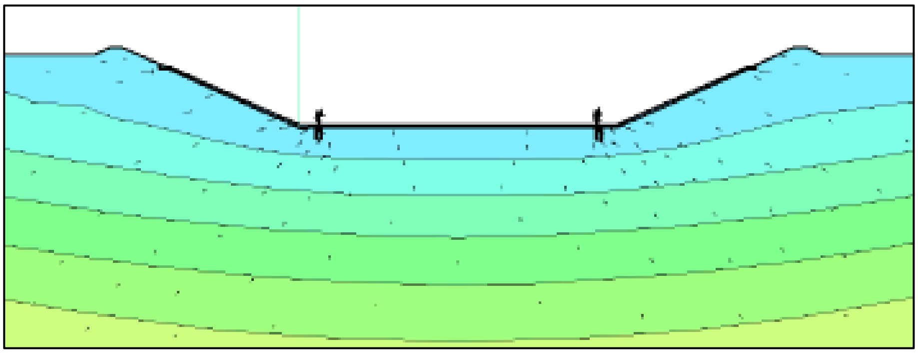


Figure 10. Results of SEEP/W with provision of PRVs near both edges of canal bed

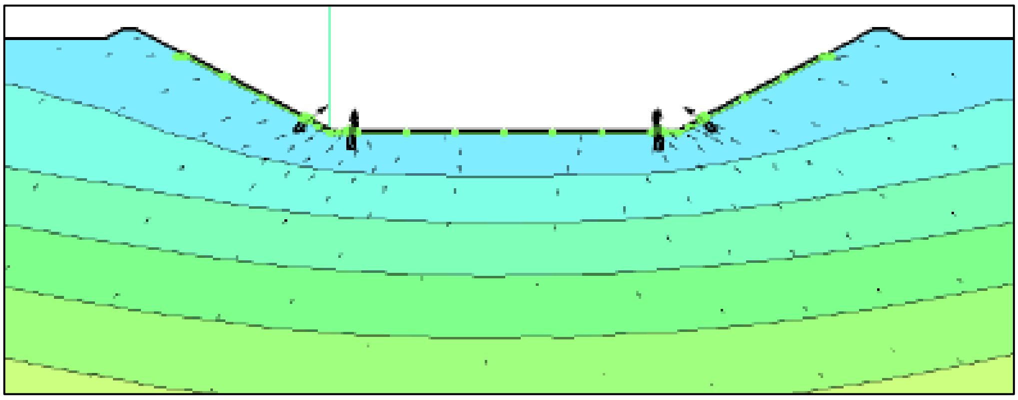


Figure 11. Results of SEEP/W with provision of PRVs near both edges of canal bed and over side slope

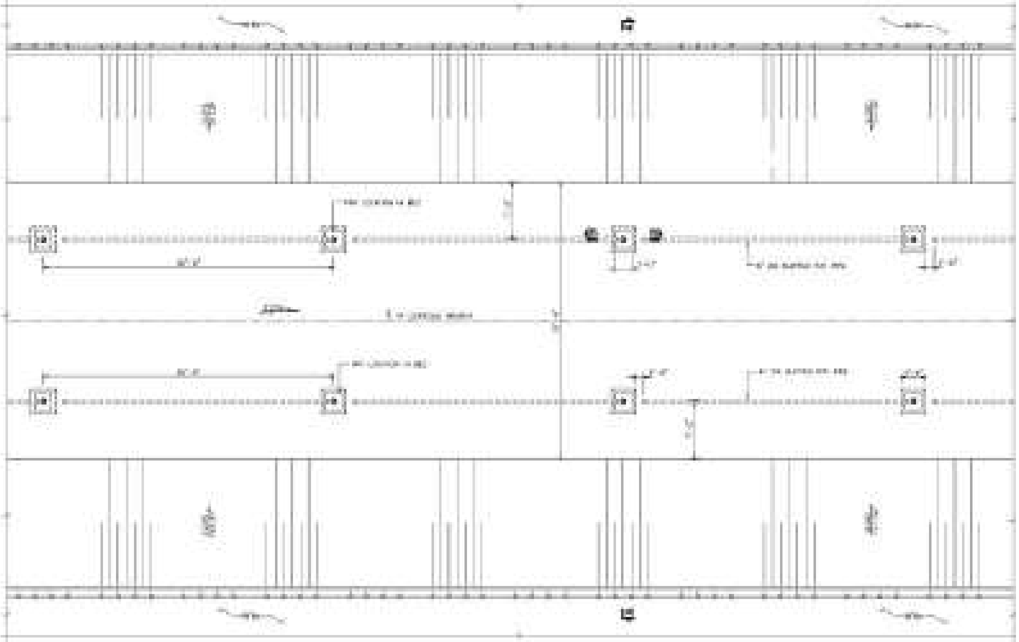


Figure 12. Layout Plan of Proposed PRVs near edges of the Canal Bed

Provision of Pressure Relief Valves (PRVs)

During formation of bed for canal lining, reasonable sloughing was witnessed from RD 109+000 to 111+000 as shown in Figure 13. Hence installation of PRVs and PVC pipes was suggested immediately under the canal bed for the same reach.

Figure 13: Observed Sloughing during Bed Formation

PRVs have been installed over pocket filled with graded filter underneath the lining as shown in Figure 14a. Graded filter was placed carefully in the pocket and compacted to form an even bedding for canal lining. The number of ditches were excavated along the canal bank during construction to give a relief pocket to the adjoining areas from seepage. Pictorial view of one of the installed PRVs at RD 110+200 is represented through Figure 14b.

a. Bed Formation for PRV

b. Installed PRV

Figure 14. Installed PRVs at RD 110+200

Performance evaluation of concrete lining with sub-surface drainage

OLB was experiencing considerable water loss and decreased conveyance efficiency prior to lining. To minimize these losses, lining of OBL was proposed along with extensive subsurface drainage system. Surrounding groundwater levels significantly reduced after lining of canal as shown in Figure 15.

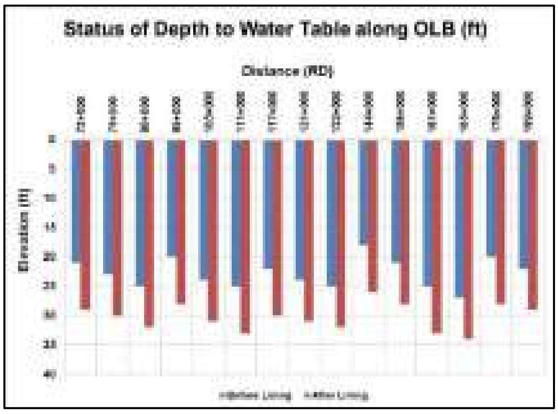


Figure 15. Impact of Canal lining over Surrounding Groundwater Levels

To deal with excessively high pore water pressure in post-lining scenario due to high surrounding ground water table, PRVs along with perforated pipes were proposed and laid instantly as described in aforementioned section The observed water levels for installed PRVs represented significant efficacy to release pore water pressure. The recorded data for one of the PRVs installed at RD 110+200 represent significant efficiency as shown in Figure 16.

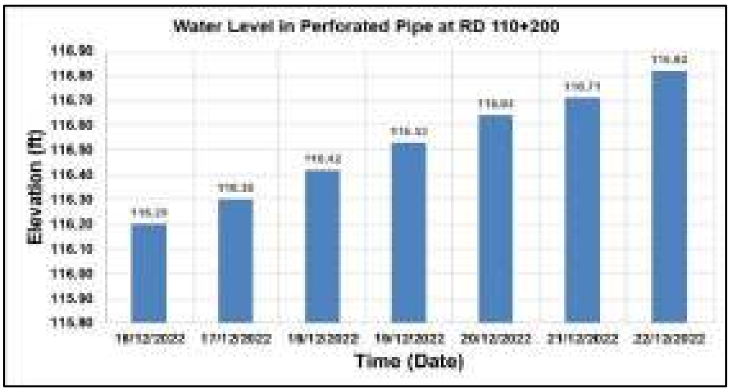


Figure 16. Efficacy of PRV at RD 110+200

CONCLUSIONS AND RECOMMENDATIONS

1. The Odero Lal Branch (OLB) Canal functions as an earthen canal that serves as a drainage channel during periods of canal closure, having the elevated water tables in the adjacent area. To adhere to the existing natural draiange, the canal has been lined to improve hydraulic efficiency. Additionally, the natural drainage patteren has been modified through the implementation of sub-surface drainage, utilizing gravity flow mechanisms. This comprehensive approach ensures both improved functionality and the preservation of natural drainage patterns.
2. The proposed interventions I,e lining of canal (OLB) has yielded substantial improvements in its conveyance efficiency. This enhancement has played a pivotal role in ensuring the consistent and designated water supply to the tail reaches of the canal.
3. The challenge posed by the elevated groundwater table in the surrounding area cannot be ignored, especially in light of the notable sloughing observed within the prism during the bed formation process for lining. Addressing this issue is imperative to ensure the stability and effectiveness of the project.
4. It was concluded that significantly high-water table relative to canal bed imposed excessively high seepage pressure over canal prism, with significant impact during empty condition of canal
5. A proper subsurface drainage system has been proposed accordingly, giving through considerations to following factors
    - Reaches were identified taking into consideration the linking of existing drains for disposal of sub-surface drainage system
    - Drainable discharge was calculated employing the SEEP/W software for identified reaches
    - Sub-surface system comprising of laterals (in transverse direction to the canal flow), collectors (parallel to the canal flow), transverse pipes (to join collectors), manholes and RCC collector & conveyance pipes.
6. PRVs were further suggested for extremely critical reaches and analysis was performed for PRVs to evaluate their efficiency with respect to their placing position. From results it was concluded that the optimal orientation for placing the PRVs was near the edges of canal bed on both sides.
7. A per data, installed PRVs represented good results pertinent to their efficiency to release pore water pressure.

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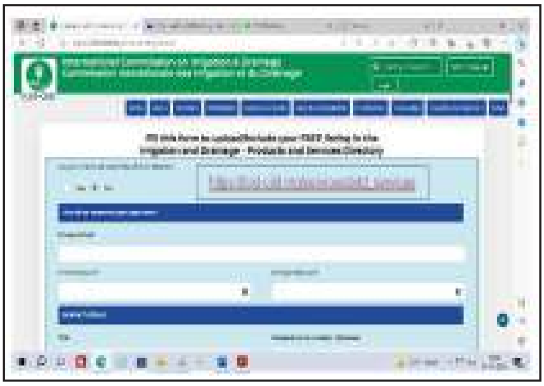

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Question 64: **What alternative water resources could be tapped for irrigated agriculture?**

Quelles ressources alternatives en eau pourraient être exploitées pour l'agriculture irriguée?

Question 65: **Which on-farm techniques can increase water productivity?**

Quelles techniques agricoles peuvent augmenter la productivité de l'eau?

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