Guidelines for Channel Coverage in Egypt: Experience Aspects and Alternative Solutions

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Abstract - Since approximately 1990s the Ministry of Water Resources and Irrigation of Egypt covered some of open channels (canals and drains) with specialized structures that may be referred to as "channel coverage" structures for two major reasons including: (1) protecting the watercourse in residential areas; (2) widening the roadway. However, these structures have differ features other than any crossing structures. Unfortunately, building a channel coverage structure has hazards that have an adverse effect on ecosystems, infrastructure, social systems, and channel hydraulic behaviours, among other aspects of life. A deficiency of design principles and information prevents many channel coverages from accomplishing their goals. Therefore, before providing channel coverage structure, all feasible options must be taken into account. Actually, there are not any description, guidelines or design vision for this type of structures. As a result, this work offers descriptions, facts, recommendations, and creative suggestions for channel coverage based on scientific and real-world experiences.

***Keywords*—Channel coverage; Coverage descriptions, Guidelines, Alternative solutions.**

I. INTRODUCTION

In Egypt, the Ministry of Water Resources and Irrigation (MWRI) has implemented and covered specific open channels with structures referred to as “channel coverage” structures for specific purposes. Channel coverage has been implemented for two primary purposes: (1) it protects watercourses in residential areas or highly polluted zones from illegal dumping of wastes, which has detrimental impacts on water and the environment; (2) it allows for the expansion of roadways to alleviate traffic issues or enables the utilization of the channel surface area for local social activities. The coverage structure of channels typically follows a closed box structure or pipeline design characterized by lengthy dimensions spanning several kilometers. These structures are primarily utilized to facilitate the transportation, distribution, and collection of flow within a specific section of a channel, such as a canal or a drain (Fig.1). For maintenance purposes, the coverage structures are separated by manholes at a certain distance due to their excessive lengths. Single or multiple barrels of channel coverage are applied with pipe and box sections in sizes that are readily available. If the coverage part has intakes/offtakes along its barrel, it distributes the discharges to the minor canals or collects the flow from the distributary drains. Channel coverages and crossing structures such as culverts, siphons, bridges, and aqueducts differ. Crossing structures are designed to transport the flow at locations where a flow obstruction or obstruction occurs, whereas channel coverage is not typically constructed for this condition. Currently, there is a lack of a comprehensive description, practice, design, or vision for this particular category of structures. Consequently, significant risks and hazards may arise as a result. Therefore, this research aims to provide descriptions, information, guidelines, and suggested innovative alternatives for channel coverage based on scientific and practical experiences.

II. DESCRIPTION OF FLOW WITHIN CHANNEL COVERAGE

The flow along the coverage barrel is observed as open channel flow with a free surface more than pressured flow. Depending on crop needs and water demands, the flow rate fluctuates between maximum and minimum discharges throughout the year. In addition, many small canals are operated using the irrigation rotation technique. For any channel coverage, entrance conditions may vary between submerged and unsubmerged flow views, which in our case is primarily based on changes in discharges, degree of blockage, and barrel sizes and lengths. Blockage accumulation can significantly alter the flow conditions, indicating apparent situations. The following factors may influence the flow through channel coverage:

- Coverage size
- Blocking accumulation
- Length
- Manhole conditions
- Changes in flow rate
- Intakes/offtakes along the barrel
- Side connections
- Bends and changes in cross-sections
- Slope
- Roughness or flow resistance
- Tailwater depths

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- Downstream conditions

Fig. 1. Overview of channel coverage.

III. DESCRIPTION OF COVERAGE SHAPES

Coverage of channels, which are widely described by their shape, has typically been constructed in single or multiple barrels with commonly used shapes of circular and box sections in the available range of sizes (Fig. 2). The selection of shape is mainly based on the construction costs, the limitations of design, and the feasibility of implementation. Reinforced concrete is utilized to construct both box and circular barrels. There is a wide range of sizes and designs when it comes to channels, ranging from narrow to large cross-sections. However, there is no consensus on the specific criteria that define channel coverage. The circular cross-sectional shape is commonly employed for the purpose of pipe covering. Due to the pipe barrel's long length, manholes are typically constructed at a certain distance along the total length of the barrel, which generally leads to more hydraulic losses. Whilst, the design of manholes for the box section, whether rectangular or square in coverage, remains consistent with unchanged barrel cross-sections.

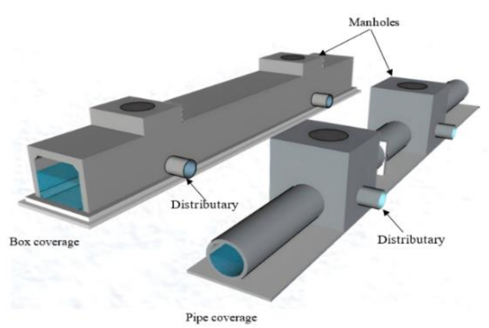

Fig. 2. General details of box and pipe channel coverage with manholes and distributaries.

IV. RISKS ASSOCIATED WITH CHANNELS COVERAGE

While channel covering has been proposed as a potential solution for addressing specific public issues, it is regrettable that this approach has had detrimental effects on various aspects of life, such as the social system, ecosystems, infrastructure, and the hydraulic behavior of channels. In 2019, a significant incident involving channel broadcasting with detrimental outcomes occurred in Sinnuris, Fayoum. The pipe coverage situated within the Bahr Tersa canal experienced an abrupt obstruction caused by debris lodged within the barrel, the specific location of which remains unknown. Consequently, the removal of this obstruction posed considerable challenges as rapidly increasing upstream water levels and out-of-canal flows occurred, resulting in severe and continuous flooding that caused damage around surrounding areas. Due to the difficulty of removing the interior obstruction, the covered canal was entirely destroyed, resulting in significant economic losses. In most cases, accumulation of debris or siltation inside the coverage body and causing a partial or complete blockage is the primary hazard related to installing coverage. Among the risks associated with installing channel coverage are:

A. Blockage of a Channel Coverage

Blockage issues relating to coverage have a significant risk with harmful consequences (Fig .3). These blockages can arise partially or fully at the inlet structure or inside the barrel. Regarding the material accumulating, both debris and siltation describe the buildup of blockage in the coverage. Trash or debris in watercourses entering a coverage may accumulate inside the barrel, causing a blockage that is difficult to remove. In addition, silt deposits can arise upstream and inside the barrel. During low flow, flow velocities reduce, and consequently, sediment depositions accumulate. Various culvert studies have been done regarding blockage effects [1-6]. There are several risks associated with the installation of channel coverage, which include:

- Rise in upstream water elevation.
- Increasing the risks of flooding and embankment failure.
- Difficulties in transporting the flow to the channel end.
- Reduction in flood storage.
- Increased in local head loss due to blockage.
- Obstruct the flow path according to the degree of blocking.
- Motivate silt deposition due to low flow velocities caused by the obstruction.
- Inadequate coverage capacity of the flow.
- More significant difficulties in removing the inside barrel blockage.
- High costs for maintenance activities, inspection, and repair.

EA [7] describes the factors that influence the amount of debris accumulating in culverts and the associated risks. Due to the resemblance of its physical structure to a culvert, these factors can also affect the channel's coverage. While channel coverages have additional characteristics beyond culvert structures that influence barrel blocking, as previously discussed. Risk factors affecting debris accumulation at channel coverage are outlined in Table 1.

TABLE 1. FACTORS AFFECTING DEBRIS ACCUMULATION AT CHANNEL COVERAGE

Coverage feature	Risk and description
Length of coverage	The risk of debris accumulation rises as barrel length increases. The long barrel is a feature for channel coverage. This feature is considered one of the most significant risks related to coverage.
Size of barrel	Narrow size is a significant issue as it produces much more risks. While culvert size decreases, the likelihood of debris buildup rises.
Coverage shape	Pipe shapes are prone to blockage more than box-shaped [8].
Manholes	The existence of a manhole changes the barrel section and consequently increases the risk of blockage. This risk is related to pipe barrels with manholes due to the change in cross-section. In contrast, a manhole for a box shape is usually designed with the same box barrel section.
Number of barrels	Multiple barrels increase the chance of a blockage.
Bends	The possibility of blockage is higher for bends. Large particles of debris can become caught in bends.
Side distributary connections.	Diverting the flow streamline with floating debris through the side distributary connections to minor canals increases the potential of debris trapping at the entrance of side connections.
Flow rate	Reduction of flow rate also reduces the velocity, leading to more sediment deposition and debris accumulations.
Hydraulic design	More often than not, full-flow design coverage will result in confined debris rather than a free surface.
Roughness/surface of construction structural.	A smooth barrel surface is less likely to cause trapped debris than a rough surface or with structural protrusions.
Downstream conditions	Existing structures such as a pump station, weir, and regulator near downstream the channel coverage can reduce the velocities within the barrel due to the backwater effects. As a result, sediment deposition and debris accumulations can significantly occur within the barrel. Constructing the coverages near the channel's end also has the same behavior.

Fig. 3. Debris accumulation upstream covered channel.

B. *High Total Head Losses*

High head losses are related to installing coverage of channels more than any crossing ones. If installed, culverts have losses, including inlet, outlet, friction, bend, junctions, and screen [9]. Several studies have defined culvert performance under various conditions [10-14]. Channel coverage has a similar loss as culverts. However, they differ, as the barrel could be extended for long lengths and separated by manholes. The components of hydraulic head losses for channel coverage are described in Table 2.

Specifically, the length of coverage has a substantial effect on total hydraulic head losses. In favorable conditions, friction losses can be considered the most significant head losses due to coverage caused by length, as the greater the length, the greater the losses. Whilst, inlet, outlet, and rack (clean rack) losses are minimal. If the coverage includes manholes (in pipe sections or changes in cross-section), side offtakes/intake within the barrel, bends, and joints, additional losses will be a factor. Moreover, once the coverage is constructed, blockage is likely to occur and may result in significant additional head losses depending on the degree of blocking. The obstruction may develop at the coverage trash rack, upstream inlet, or within the body. Hydraulic losses can dramatically alter the water levels within the channel coverage, which may affect the distributary levels for offtakes and intakes along the barrel. Consequently, the water profiles must meet the requirements of the distributary levels.

C. *Difficulties in Maintenance Activities and Providing New Connections*

Maintenance in this context refers to removing any flow obstructions, such as debris and sediment deposition, and keeping the coverage clear so the flow can always pass through. Channel coverage inspection and maintenance require special equipment and procedures, producing more difficulties and costs than open channels. Maintaining a structure with a closed shape and long barrel lengths may be complicated. Compared to open watercourses, the maintenance and inspection difficulties for channel coverage may be affected by the factors listed in Table 3. In contrast, providing new drain outfalls or connections to the coverage is more complex than for open watercourses. In certain instances, surrounding areas require new drainage systems, which necessitates the attachment of new connections to the barrels. In addition, these challenges can extend to the maintenance of interior barrel connections.

TABLE 2. HEAD LOSS RELATED TO CHANNEL COVERAGE

Component	Description
Rack head loss	The rack upstream inlet induces loss when the flow passes through it (if installed).
Inlet head loss	The contraction of flow induces loss as the flow contracts from the watercourse into the coverage.
Friction head loss	The length of the coverage barrel induces a significant loss. The more barrel length, the more friction of the barrel surface occurs.
Manholes head loss	The hazard of manholes occurs in pipe coverage, as the manholes change the pipe cross sections, and therefore the losses occur.
Bends and transition within coverage loss	Due to the greater length of the barrel, the potential of bends and transition within a coverage can exist and result in losses.
Side offtakes/intakes loss	Additional losses will result if the channels' coverage contains side offtakes/intakes or openings.
Outlet head loss	The flow expansion induces loss as the flow expands from the coverage into the watercourse.
After construction	
Blockage head loss	Once the channel's coverage is installed, the probability of blockage within the coverage significantly occurs, causing major losses. The head loss generally depends on the degree of blocking. From field experiences, the blockage may also occur within the coverage at the upstream and inlet trash racks. In addition, the rack itself can cause blocking by accumulated debris at bars.

D. Diminish Collecting the Excess Water From Surrounded Lands

During the closing period (no discharged flow), one of the purposes of the canal is to act as a drain that collects percolated water from the surrounding lands. Due to the material used for the barrel lining, however, construction channels can significantly reduce this function. As a result, waterlogged conditions, wetlands, or standing water on fields may develop near the coverage, resulting in a loss of soil fertility.

E. Impacts on Water Quality and Pollution

The coverage has logically shown the similar effects of culverts on water quality due to the similarity in body construction. Due to the length of the barrels, coverage structures may also produce more severe impacts. Typically, culverting a watercourse reduces the oxygenation of water passing through a barrel and disrupts the biological processes that contribute to water purification [15]. In addition, culverts are frequently highly polluted due to improper connection of sewage systems [16]. Illegal sewer connections may be connected to the barrel, leading to more water pollution. Moreover, covered sections can significantly complicate inspection and reduce pollution.

TABLE 3. F ACTORS AFFECTING DIFFICULTIES IN MAINTENANCE WITHIN CHANNELS COVERAGE

Component	Description
Closed structure shape	Closed shape is the main reason that makes it greatly difficult to maintain the coverage.
Alternative maintenance method	Alternative methods of coverage maintenance are complex, expensive, and time-consuming. Due to its closed shape, cleaning the interior of a barrel requires special procedures and equipment. Occasionally, removing interior blockage may necessitate much more complex maintenance.
Prediction of blockage	It is difficult to predict how quickly a barrel will become blocked and to define the level of blockages within the policy. Unexpected blockages can occur at any time, and in some instances, they can develop more quickly. For instance, maintenance activities may be performed with great effort and high costs, but unexpected blockage may occur immediately after maintenance.
Length	The more extensive the channel coverage, the more difficult it is to remove the internal blockage.
Size of coverage barrel	Maintenance difficulty increases with decreasing barrel size. Narrow dimensions prevent manual maintenance and some equipment from entering the coverage barrel and removing obstructions.
Bends	Some equipment cannot be formed with bends, making it more challenging to perform maintenance on a coverage barrel with bends, especially sharp bends.
Irrigation rotation (working/closing period)	Maintenance and inspections are significantly more difficult during the working period than during the closing period. In the event of flowing discharges, interior inspection, manual maintenance, and the movement of some equipment cannot be carried out to their full extent or moved entirely within the barrels. From a practical standpoint, draining the coverage of water to remove an emergent blockage or conduct an inspection is more complex, time-consuming, and expensive.
Manhole sizes	The smaller the manhole throat, the more difficult it is to perform maintenance. Inadequate manhole throat dimensions can prevent buckets attached to hydraulic excavator arms from entering and clearing manhole blockages.

F. Hazards for Health and Safety and Environmental Features

EA [15] noted a lack of oxygen or the development of potentially explosive or toxic gases within culverts. Additionally, a significant number of children have died or been injured after entering culverts, representing a grave safety risk. Moreover, water cover results in significant loss of environmental and habitat features. As landscape changes, certain species' ecological status and migration are negatively impacted. The installation of culverts degrades the landscape features.

G. Abrasion and Corrosion of Barrel Material

Blanc [17] noted in her review that abrasion and corrosion are significant issues for barrel materials. Abrasion is the deterioration of barrel material caused by sediment movement within streams. Also susceptible to corrosion are metal and concrete materials. Water and soil may contain acidic and alkaline conditions that could lead to metal corrosion. Saltwater environments can cause concrete barrels to react with carbonates and sulfates in the soil. In addition, they are sensitive to the combination of water and sulfur dioxide that anaerobic bacteria produce.

H. Erosion Hazards at Outlet Structure

The outlet structure could facilitate the transition between the barrel and the downstream watercourse. Scour is a typical occurrence at culvert outlets. At culvert outlets, two types of scour can occur: (1) local scour and (2) general channel degradation [18]. Numerous research on scouring at culvert outlets under various circumstances have been conducted [19-22]. Typically, the flow area of the covering part is smaller than the stream flow area, resulting in much more flow velocity at the structure exit and causing local scour.

As previously discussed, the risks associated with channel coverage have detrimental impacts on hydraulic, environmental, and economic values.

V. PROPOSED ALTERNATIVES TO MITIGATE RISKS RELATED TO COVERAGE OF CHANNELS

Channel coverage should not be considered the best solution to a specific issue, as is sometimes thought. Occasionally, decision-makers believed covering the channel was the correct answer to eliminate an issue. However, coverage structures themselves can indeed result in serious issues. All viable options must be considered before deciding whether to provide coverage for the watercourse. The following alternatives to channel coverage are proposed to eliminate the associated risks:

A. Identify the Options

Identifying options include do nothing, reduce the cause of the problem at the source.

1) Do nothing

In order to avoid the perceived risk, the "do nothing" option is encouraged to be the first choice (Fig.4). The channels that pass through residential blocks remain a recreational area in rural and urban areas. Utilizing urban water as a local landscape and green amenity space to increase access to recreational activities such as walking and fishing is a viable option. Additionally, daylighting (replacing existing coverage with an open channel) is an option when it is reasonable to do so in order to eliminate the risks.

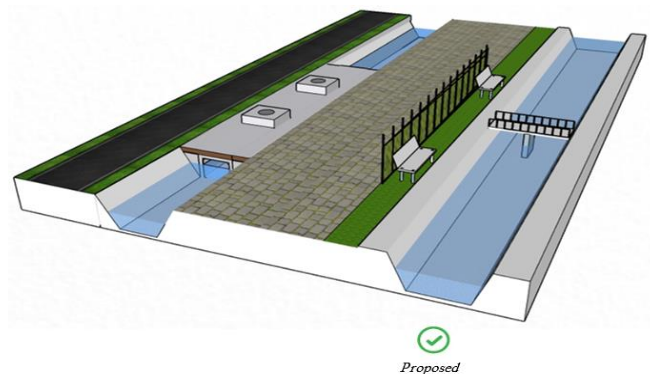

Fig. 4. Proposed open cross-section instead of covering the channel.

2) Reduce the cause of the problem at the source

Effective mitigation measures that eliminate the risk of a problem at sources are far more successful than those that only address its consequences. Covering a part of the channel sometimes has short-term advantages compared to disadvantages. Reducing litter and fly-tipping is subjected to the short-term advantages of coverage. Such an advantage can be pursued by alternative means to address rubbish problems in open channels. It is essential to consider possible ways to reduce the debris load transported within the watercourse. Illegal dumping is one of the reasons that led to the construction of coverage structures within streams. Channel coverage cannot prevent illegal dumping over a channel. Logic dictates that if illegal dumping can be prevented after installing coverage, it can also be prevented in the case of an open watercourse. The reduction of illegal dumping and debris loads, such as household waste, can be accomplished by a number of proposed alternatives, including:

- Enclosure of the watercourse: Rather than covering the watercourse, enclose it with a wall, fence, green fence, or living fence (Fig. 5).
- Finding alternative measures for household waste: Household waste is the primary source of the problems. For that, household waste collection and disposal must be handled by local authorities. Additionally, proper alternative sites should be prepared for fly-tipping hotspots.
- Public awareness campaign: It is possible to reduce household waste in urban areas by public awareness for riparian owners.
- Enforcement action: Local authorities may need to apply legal enforcement actions to limit household waste.
- Utilizing cameras for monitoring.
- Divert the pathway of the watercourse if practically and reasonably possible.

Fig. 5. Photo of utilizing watercourse for recreational opportunities rather than the covering.

B. Design and Install Channel Coverage

The risk posed by a well-designed coverage should not be more severe for engineering safety considerations than the open channel it replaces. The hydraulic design of channel coverage should have specific provisions and considerations due to its unique features rather than culvert designs. The culvert's structure length is 20 feet (6.1 m) or less [23], while channel coverage extends for long lengths. In particular, the long length of coverage structures resulted in several risks, increasing the potential of bends and difficulty in safely transporting floating debris downstream without interior accumulations. In addition, blockage losses should be considered in the design by assuming the probability of blockage for safe operations and adequate capacity. Therefore, careful design consideration of the coverage structure is required for appropriate operations and to mitigate the related risks. Coverage inlet and outlet design is also required to enhance the operation performance. The proposed alternatives must not compromise the structural integrity of the coverage. Therefore, such alternatives should not be accessed without a structured design to ensure construction safety. The following suggestions are proposed for the design of channel coverage.

1) Increasing coverage size

Larger sizes for coverage have the advantages of mitigating the blockage accumulation inside the barrel, decreasing the degree of blocking compared to the narrow sizes at the same amount of debris, allowing the transport of more water with a bigger size, and facilitating maintenance access at any time (Fig. 6). HWA [24] recommend that a culvert be at least 1.2 m in diameter when it is longer than 12 m to facilitate maintenance operations. However, 1.5 or 2 m minimum dimensions are recommended for coverage width and height. This finding is due to the unique features of such structures, as discussed previously. Furthermore, the maximum contraction of the watercourse due to the presence of coverage structure is proposed to be 20 -30% or less to avoid a significant increase in backwater rise.

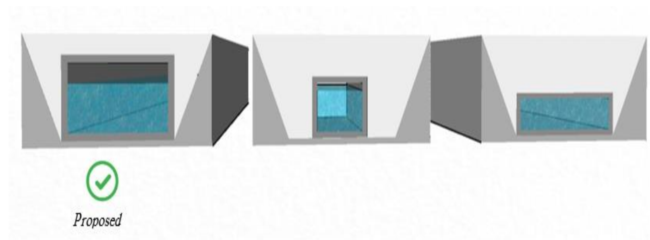

Fig. 6. Proposed larger size for coverage instead of narrow cross-sections.

2) Use box cross-sections

Box cross-section (rectangular or square) coverage can be easily modified to fit a variety of site requirements. Box shapes are proposed rather than pipe shapes due to the following reasons:

- Manholes within the structures for pipe shape change the barrel cross-section, producing hydraulic losses, whereas they are designed with the same box barrel section, resulting in non-hydraulic losses due to manholes.
- Box shapes have more space, that feasibility access for maintenance activities, enabling adequate mechanical machines, and handling maintenance within the barrels compared to the pipe shape.
- Pipe shapes are prone to blockage accumulations due to reduced free surface [25].
- Box shapes allow larger flow capacity and then reduce flood risks.

The advantages of low cost for pipe shape construction are considered limited compared to the disadvantages resulting after construction.

3) Design to support vehicles weight and pedestrians

Channel coverage is used to transport the flow but must be structurally designed to support the vehicle's weight and pedestrians. Channel coverage is constructed within residential areas to be used as a vehicle's garage and/or installed to enlarge the roadway. Consequently, the weight of vehicles and pedestrians should be considered in the design. Therefore, along with the hydraulic design of channel coverage, structure design should be taken into account.

4) Use movable precast concrete lid

Installing the channel coverage as U-shaped sections and cover lids is proposed to have the ability for lifting the coverage lids and access easily to the maintenance at any time (Fig .7). Steel hooks attached to the cover lid and lifting cables are used as a proper lifting to avoid cracks. Lifting the coverage lids can turn the closed conduit into open channels. Therefore, the features of the open channel can be obtained.

Removing the inside barrel clogging for closed coverage is often complicated, and the interior blockage's location is unknown, leading to damage to the barrel at the end. Such issues for U-shaped sections and cover lids can be avoided. Therefore, the proposed lifting cover lids for U-shaped sections may have the following advantages rather than a totally closed conduit.

- Converting the closed conduits into open channels and having features of them.
- Allowing access for interior maintenance and removing any clogging at any location inside the barrel.
- Facilitating the use of conventional maintenance equipment that is simpler to utilize in open channels than in closed conduits.
- Lowering maintenance costs as a result of avoiding the use of the complex machinery used for closed conduits.
- Facilitating the inside inspections for structural frame conditions and the cover lid to detect any concrete cracks, corrosions, or unexpected changes.
- Supporting ventilation or aeration to reduce losses of biological systems. Therefore, scheduling the need for coverage ventilation can be a part of the operation systems.

For safety considerations, stability of the cover lid is significantly required to avoid any unexpected budges or movements of lids. Screen lids below the main concrete lid may be attached to trap any unexpected fallings or failures.

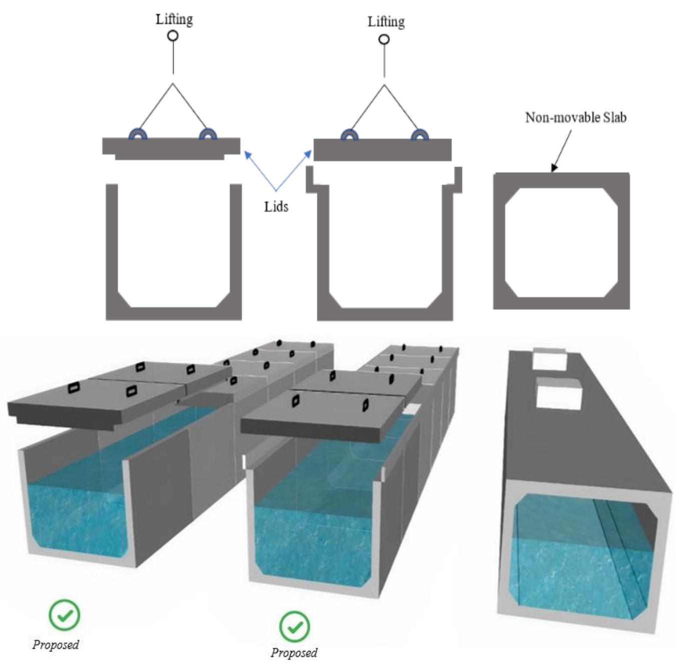

Fig. 7. Proposed movable precast concrete lid for coverage instead of non-movable slab.

5) Minimizing the barrel length and avoid bends as possible

Compared to shorter barrel lengths, extended coverages are associated with several dangers, as follows.

- Produce more major hydraulic losses.
- Enhance the probability of inside blockage.
- Increase the potential of the existence of a barrel within bends.
- Make maintenance procedures more difficult.
- Leads to high maintenance costs.
- Increase the potential losses of biological systems and oxygen and enhance water pollution.

Therefore, minimizing the barrel length is proposed to avoid the previous risks related to long barrels as possible. Additionally, constructing barrels within bends increases risks due to the possibility of blockage and hydraulic losses. Consequently, avoiding channel bends is proposed to diminish the related risks.

6) Increasing manhole cover sizes

In contrast to narrow dimensions, larger sizes of manhole covers are suggested to ensure optimal maintenance operations (Fig. 8). Larger sizes provide more spaces that enable excavator buckets or any maintenance tools to easily enter and lift the inside blockages. Moreover, minimizing the distance between manholes for the box shape is also proposed (does not exceed 20 m when the cross-sections of the manhole are the same as the box shape).

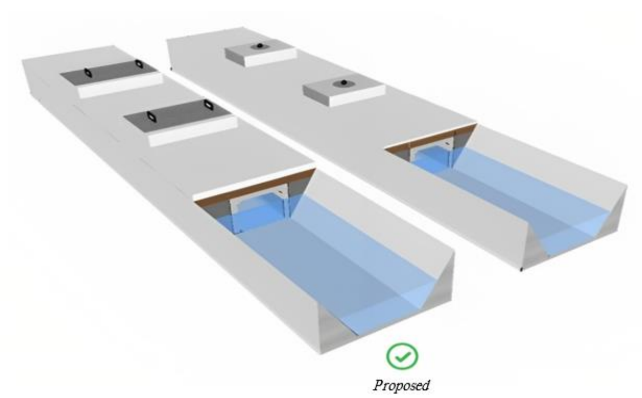

Fig. 8. Proposed larger size of manhole for coverage instead of a narrow one.

7) Use single barrel instead of multiple barrels

Regarding the coverage structure characteristics, using a single barrel with a large size is proposed instead of a multi-barrel with a small size (Fig. 9). Multiple culvert barrels are susceptible to restricting debris flow and clogging [25]. While the coverage barrel is longer, it can present obstacles along its length. Therefore, a single barrel is recommended wherever it is feasible to improve debris passage with a lower potential for clogging.

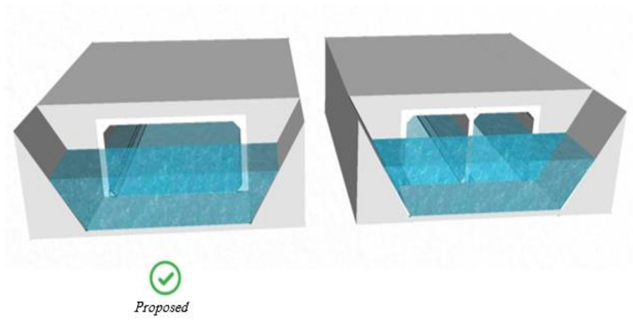

Fig. 9. Proposed single barrel instead of multiple barrels.

8) Provide trash rack and barrier

Providing trash racks and barriers for upstream channel coverage is necessary since blockage, long barrels, and maintenance difficulties with high costs are critical hazards relating to channel coverage. Installing a rack is a proactive move to diminish the potential inside blocking by floating materials (Fig. 10). Trapping floating debris upstream enables the excavators to lift debris easily before reaching into the interior barrel and producing removal issues.

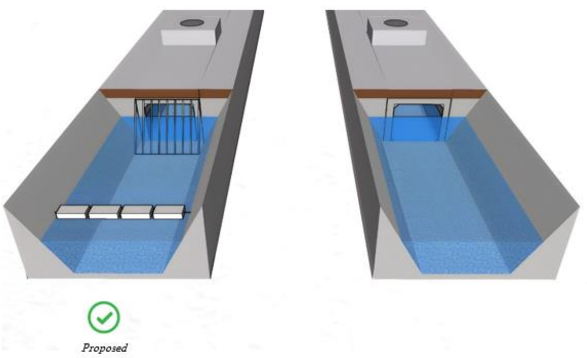

Fig. 10. Proposed trash rack and barrier upstream coverage structures.

9) Consider the hydraulic design for free surface flow

In general, free flow design provides greater coverage capacity and allows the flow to be transported through the barrel in the event of a partial blockage, compared to full flow conditions. Partially obstructing a coverage under full flow conditions raises the water level upstream, thereby increasing the risk of flooding. Moreover, designing for full flow frequently results in debris confinement more than a free surface.

10) Design with considering blockage loss

Blockage is a major issue related to channel coverage. It occurs after construction and can result in adverse effects. Therefore, hydraulic losses due to blockage of channel coverage should be considered in the design to mitigate the related hazards.

11) Avoid the construction at contracted cross-section

The cross-section of a canal can occasionally be observed to be contracted at the upstream coverage structure (Fig. 11). When a flow moves from a wide to a narrow cross-section, the velocities inevitably rise and scour is potentially possible. In addition, the entrance losses increase as the velocities increase. Channel contraction may be developed due to many reasons, such as the ignorance of canal rehabilitation upstream of coverage or changes in the longitudinal cross-section from one location to another. Therefore, channel rehabilitation upstream of such a structure is required.

Fig. 11. Contracted cross-section upstream covered structure causing local scour.

12) Provide headwalls, wingwalls, and protection

Headwalls increase inlet and outlet performance, provide embankment stability, and protect against erosion and buoyancy. Additionally, wingwalls have the benefits of ensuring the stability of the channel side slopes, particularly in a skewed location, protecting against erosion, and enhancing performance. Consequently, headwalls and wingwalls are proposed for the construction of the coverage. The erosion of channel coverage at the outlet is common. Therefore, the design should consider scour potential. In fact, it is reasonable to provide at least minimal protection for any unanticipated conditions affecting coverage inlet and outlet.

13) Allow for channel with bed width less than 5 m

Allowing the construction of channel coverage for channels with bed widths less than 5 m is proposed. Covering wide channels is associated with several hazards, as follows:

- The risks related to channel coverage become more complicated with increasing the degree of the channels.
- Since irrigation rotation for wide channels is contentious in the working period, maintenance tasks and inspections are more challenging than the channel with closed periods.

14) Provide air vents over the top surface

Air vents are proposed to be attached over the top surface of the coverage structure to reduce the related risks of the inside-developed gases (Fig. 12). Air vents allow the drain of toxic gases out of the coverage body and help in air circulation. Hence, the oxygen in the atmosphere enters the barrel through the vents, allowing for the possibility of reducing loss in biological processes.

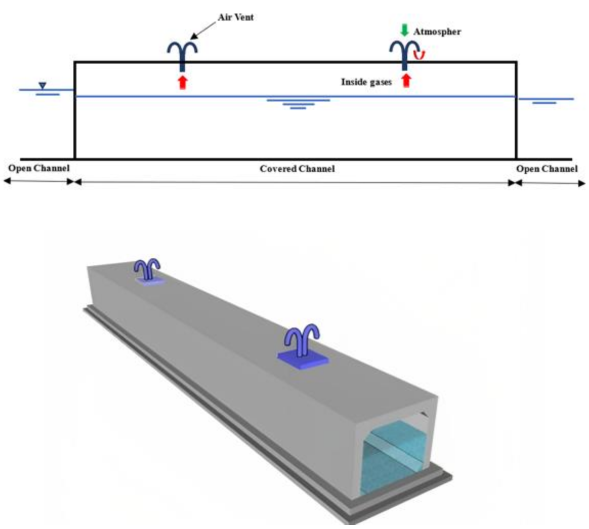

Fig. 12. Air vent attached to channel coverage.

15) Install fixed water jet systems as washing method along the interior coverage

Water jet washing systems are a proposed innovative technology to be presented for the first time as a washing method inside the coverage body (Fig. 13). The main components of water jet systems or jet washing systems are as follows:

- Water supply: is the source of water that is used for washing. Water may have small particles, chemicals, suspended solids, iron precipitates, and calcium that can clog the jets opening. Therefore, water quality is a vital criterion for a water supply.
- Pumping unit: the pump should be designed to lift the necessary amount of water from the water source to the interior coverage body.
- Main Lines: the main line conveys water to the lateral pipelines from the source.
- Lateral pipelines receive water from the main line and direct it into the culvert body through the jets. The entrance of the lateral pipelines should be closed after finishing the maintenance activities to prevent insects or reptiles from entering.
- Jet heads fitted on lateral pipes: the main component of a jet washing system is the jet head. The jet head distributes the shooting of water over the field. Therefore, suitable nozzle sizes, operating pressure, and jet spacing are required to fulfill washing efficiency. Jets can be designed either rotating or fixed. Non-return valves can be attached to jet heads to prevent insects or reptiles from entering the pipes through nozzles.
- Accessories and fittings: fittings and accessories such as water meters, pressure gauges, and flow control valves may be attached to the system to facilitate the performance.

A pressurized water jet system operates among a piping system as water is pushed under pressure. Pipelines are fixed along the interior walls of coverage at any appropriate locations and suitable arrangements to convey the pressurized water from the water source to the interior covered structure through jets. Water under pressure is pumped through flow jets (orifices or nozzles) to produce shooting spray. To enable sedimentation or debris to be pushed out, a careful selection of the inclination angle of jets with the flow direction is required. Using a fixed jet system within the coverage (also, siphon, aqueduct) is an effective, simple, and appropriate technique to clean the inside covered body. Compared with the traditional washing method, this method may overcome cleaning difficulties such as the long-distance bends of coverage and the continuous channel flow.

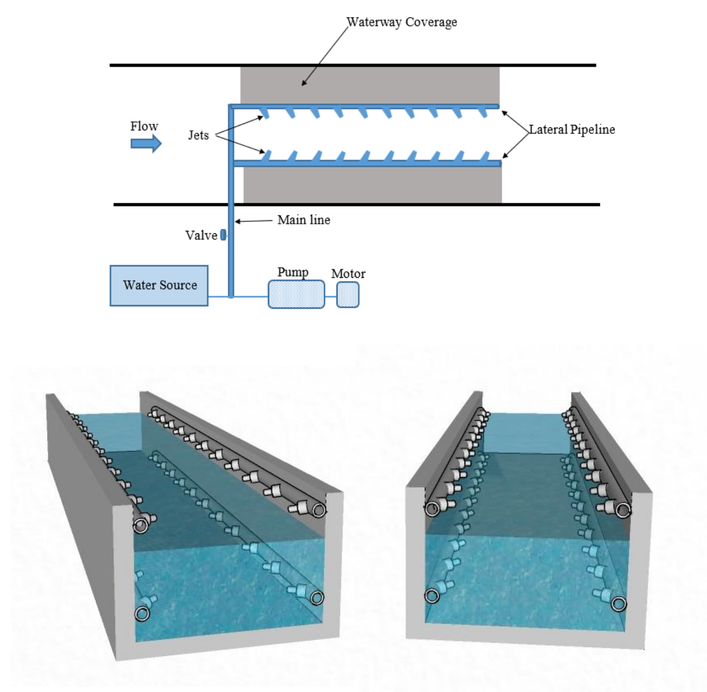

Fig. 13. Components of a proposed innovative jet washing system.

16) Provide the inner walls with shelves as roadway for a movable CCTV

A closed-circuit television (CCTV) camera is an effective inspection tool to locate and identify blockages, damages, and hidden coverage structure issues. However, the mobility of CCTV inside the coverage body may encounter movement challenges, such as obstacles and continuous channel flow, making moving more difficult. Therefore, installing side shelves (or rods) above the maximum water level inside the coverage to behave as a roadway for the movable CCTV is proposed (Fig. 14). The side shelves can be considered during the construction as a part of the concrete walls.

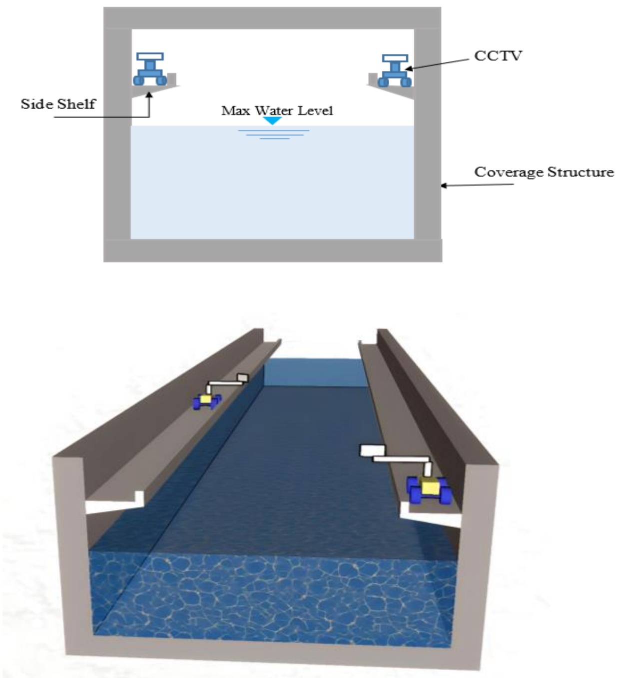

Fig. 14. Coverage structure with side shelves for movable CCTV.

17)Use a robotic cutting saw with pincer arms

Using a robotic arm with a cutting saw that can move on the inner coverage shelves (or rods) is proposed (Fig. 15). The proposed robotic cutting saw aims to cut the inner blockages into small pieces. Cutting the blockage into small pieces is sometimes required to push it out with flow direction. Sided robotic pincer arms are recommended within the robotic cutting saw to ensure the stability of the obstruction materials and prevent materials from escaping during operation. Pincer arms with angled jaws are used to capture and lift obstruction materials so they can be easily cut with a cutting saw. The design of the pincer can be modified for local use.

In addition, pincer arms or buckets without saw may be also used to remove blockages and floating materials from the barrels using movable carriage or hydraulic rods. Blockages and floating objects inside the coverage body can be removed from the barrels by utilizing the pincer arms or buckets which are fixed to movable carriages or hydraulic rods, that can enable the pincer arms or buckets to move out of the coverage body. The cleaning process is cyclic.

- Lowering of pincer or buckets to the bottom.
- Catch the materials and hoist blockages from the water.
- Move out of the structures the carriages or hydraulic rods with the blockages.

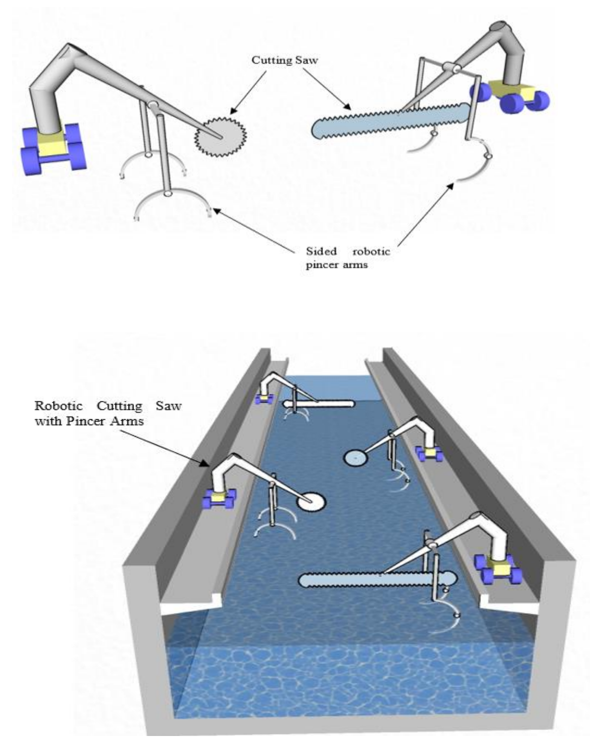

Fig. 15. Robotic cutting saw with pincer arms.

18) Provide pressure release valve

The coverage structure is proposed to be provided with pressure release valves to improve the collection of percolated water from the surrounding lands and protect the barrel lining from hydrostatic pressure.

19) Checks after design

As the channel coverage can be extended over a long distance and they have connections (intakes/offtakes) along their barrels, essential checks are required after design. Namely, coverages transport the flow, distribute the water according to the altered water level, and have particular specifications. The following checks are suggested after the design.

- Check head loss considering all losses stated in Table 2 as well as the potential blockage losses.
- Check the construction design for safety.
- Check the downstream velocity.
- Check the freeboard for upstream coverage.

- Check the water level within the barrel for minimum and maximum flow requirements to fulfill the required connection level (intakes/offtakes or drain collectors).

20)Maintenance, monitoring and recording

It is recommended that operators responsible for channel coverage perform regular inspections, maintain records of cleaning frequency, document the types and quantities of materials removed, and report any coverage issues that may have arisen. This will facilitate maintaining or upgrading the channel coverage in the future.

Regarding reviews for culvert alternatives, the UK culvert guide for design and operation discourages installing new culverts due to the related harmful effects [26]. Furthermore, daylighting is encouraged to avoid culvert risks [7]. EA [7] suggested the use of community engagement and awareness, cameras for regular monitoring, and closed circuit television (CCTV) and telemetry to detect rapidly rising water levels as methods for reducing safety risks associated with culverts. Balkham et al. [26] proposed alternatives to culverts, which may include the following:

- Relocating the infrastructure somewhere else to eliminate the requirement to cross a channel.
- Bridges or fords may be utilized instead of culverts.
- Diversion of watercourse is an alternative to culverts.

VI.CONCLUSIONS

This research aims to provide guidelines, explanations, information, recommendations, and suggested innovative alternatives for channel covering based on scientific and real-world experiences to alert designers and decision-makers to the right option. Unluckily, constructing a channel coverage structure is related to risks that negatively impact many facets of life, including the social system, ecosystems, infrastructure, and channel hydraulic behaviors. Therefore, all viable possibilities must be considered before offering channel coverage. Due to a lack of design guidelines and information, many channel coverages are unable to achieve all of their objectives. If the ultimate decision is to install channel coverage, the research proposed a number of innovative techniques and recommendations for designers.

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